A SOLID STATE DIGITAL DATA RECORDER FOR MONITORING AUTOMOTIVE CRASH ENVIRONMENTS

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16. Abstract

A solid state digital data recorder has been developed for use in monitoring automotive impact environments. The recorder was designed to be a general purpose, on board data acquisition system. Each recorder channel has its own sensor preamplifier, analog to digital converter, 4096 x 8 bit random access memory, and digital to analog converter. The functions of reading and storing data by the recorder channels are determined by a single, common control module. A nine channel system was evaluated via a pneumatic shock machine, vibration testing on a shaker, 30 mph sled simulated vehicle-barrier impacts and 30 mph vehicle barrier impacts.

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While this activity was sponsored by NHTSA the findings, opinions and conclusions expressed in this report are those of the author and not necessarily those of the involved agency.

TABLE OF CONTENTS

A SOLID STATE DIGITAL DATA RECORDER
FOR MONITORING AUTOMOTIVE CRASH ENVIRONMENTS

1.0 INTRODUCTION

The acquisition of multi-channel dynamic data associated with the high energy mechanical shock environments experienced by automotive impacts is a difficult problem. It is complicated by two inherent difficulties: 1) the shock levels may be sufficiently high (>100 g's) so that linearity and in some cases survivability of the measuring device is of concern, and 2) large distances and/or high velocities may be involved. This second difficulty implies that instrumentation schemes involving trailing wires to transmit data become difficult to work with and impractical for any application where vehicle travel exceeds 100 feet or so. Telemetry schemes have been developed for automotive collision applications. These systems eliminate the need for a hard wire data line and are only vulnerable to linearity and survivability problesm at higher acceleration levels. However, in many applications high g telemetry systems require extensive antenna design and development to be compatible with physical and structural constraints. Also, in some cases where the vehicle overturns or water impact is involved, no path is available over which electromagnetic waves having the frequencies ivolved can propagate. As a result, dead spots or data blackouts may be encountered. Automotive crash testing involving telemetry transmission of data tend to be very complicated and require large numbers of test personnel to carry out the required detailed checkout of the TM system.

In the last several years (since 1969), developments in low power, large scale integrated circuits allow consideration of additional concepts for high g data acquisition. Schemes where finite length analog time history records are converted into digital words and stored in a semiconductor memory within the device have recently become practical. Data is then retrieved after recovery of the test item, and the need for a TM or hard wire communication link is eliminated.

In 1976 NHTSA sponsored a program (contract DOT HS-4-00927) in which a miniature solid state recorder was developed and mounted totally within the Part 572 anthropomorphic dummy, this device was intended primarily for utilization in barrier impact testing. The application of this recorder to vehicle rollover testing was accomplished by making the analog to digital sample rate signal amplitude dependent, thereby extending the record time from ~0.4 seconds to >3.5 seconds in a typical rollover application (contract DOT-HS-6-01333).

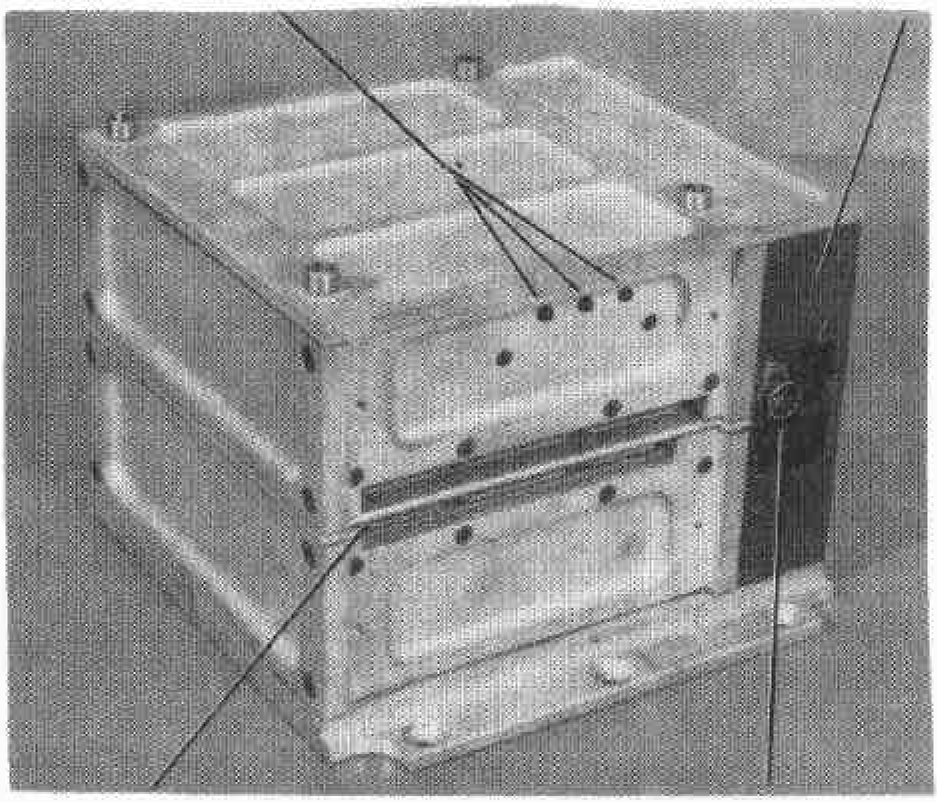
The scope of this present activity is to develop a nine channel solid state recorder having a volume of ~1/3 ft^3 and weighing 16 lbs which could be utilized for monitoring vehicle dynamics during vehicle barrier and rollover crash testing. The basic recorder design was similar to that of the dummy's recorder but a substantial effort was made to utilize electronic components and assembly techniques which were less expensive than those employed in the dummy recorder.

The overall nine channel instrumentation package is shown photographically in Figure 1.0. Program activity was separated into two portions. The first was to develop the overall system concepts and fabricate one system. The second portion of this effort consisted of test and evaluation of the nine channel system.

This document is a summary of the overall program activities culminating in a vehicle crash test series.

LIGHT EMITTING DIODE
STATUS INDICATORS

SYSTEM BATTERY
MODULE



SENSOR INPUT
CONNECTORS

BATTERY
ACTIVATION
CONNECTOR

FIGURE 1.0 PHOTOGRAPH OF THE AUTOMOTIVE VEHICLE CRASH RECORDER. PHYSICAL DIMENSIONS (NOT INCLUDING MOUNTING FLANGE) ARE ~ 7.5 IN X 7.5 IN X 7.5 IN AND OVER ALL WEIGHT IS 16.4 LBS.

2.0 SYSTEM DESCRIPTION

2.1 Operational Requirements

This solid state digital crash recorder activity is aimed primarily at developing a system for use in monitoring vehicle accelerations during barrier and rollover crashes. The SAE J211A recommended practice for instrumentation of these events requires either a 60 or a 180 class system, with event times ranging from 30 ms to several seconds. Typical acceleration levels are less than 100 g's. It is also desirable to have the vehicle recorder a totally sealed unit so as to be dust and moisture proof.

The solid state digital vehicle recorder performance objectives can be summarized as follows:

1) Number of channels - 9

2) Number of words per channel - 4096

3) Number of bits per word - 8

   Total memory - 295,912 bits

4) Analog to digital sample rate selectable - 39 Hz to 10 kHz

   Record time - 0.4 to 102 seconds

5) Trigger modes

   - Internal on preset level (3 channels)
   - Internal on preset level and duration (1 channel)
   - External

6) Data store time

- Ready mode - 3 hrs
- Retention time - up to 8 hours (depending on time in ready mode)

7) Operational environment

- Mechanical shock 100 g's - 10 ms duration (half sine wave)
- Vibration - 60 g sine wave 10 Hz to 100 Hz
- Temperature - -20[F to 150[F
- 100% relative humidity

The development of a solid state digital crash recorder to meet these objectives involved a review of the anthropormophic dummy solid state recorder. The dummy recorder provided a design base line. In addition to the design changes required to meet the performance goals outlined above effort was made to meet the following additional project objectives:

- Simplify field operation of the device wherever possible.
- Reduce component and fabrication costs wherever possible.
- Reduce and simplify cost of mechanical packaging of electronics wherever possible.

2.2 Recorder Description

The overall solid state vehicle crash recorder was designed to be a general purpose data acquisition system. It consists of a number of functional modules which, when connected together on a 36 wire parallel bus, meet a specific set of data acquisition requirements. A block diagram of the recorder system is shown in Figure 2.0. Each recording channel module is connected to the parallel bus and is totally passive. Its timing and functions are determined by the control module which drives the bus. A detailed block diagram of each recording channel is shown in Figure 2.1. Block (A) of Figure 2.1 represents the signal conditioning electronics required to interface the sensor. It also provides the necessary signal amplitude gain for scaling sensor output. Block (B) is a low pass filter which is required to prevent aliasing errors in digitized data. Block (C) converts the conditioned analog signal into digital words (A/D) at a rate which is determined by the control module. A successive-approximation A/D converter is used. Block (D) is a 4096 x 8 bit word dynamic random access memory which accepts data from the A/D converter and outputs it on the parallel bus to the parallel to serial converter (E) and to a digital to analog converter (F) within the module. Blocks (E) and (F) are employed to output data from the module either in an analog or digital format.

Figure 2.2 illustrates a block diagram of the control module which drives the 36 wire parallel bus. Block (CA) of Figure 2.2 provides the recorder system with regulated voltages of +12V, +5V and -5V to insure that battery voltage fluctuations, such as during the impacts themselves or during long periods of battery operation, do not affect system accuracy. This regulated voltage is also required for system clock stability (i.e., time base). Block (CB) generates the system clocks which are used for timing and data transfer strobing. It provides a 1 MHz clock to the bus for general use by the passive recorder modules.

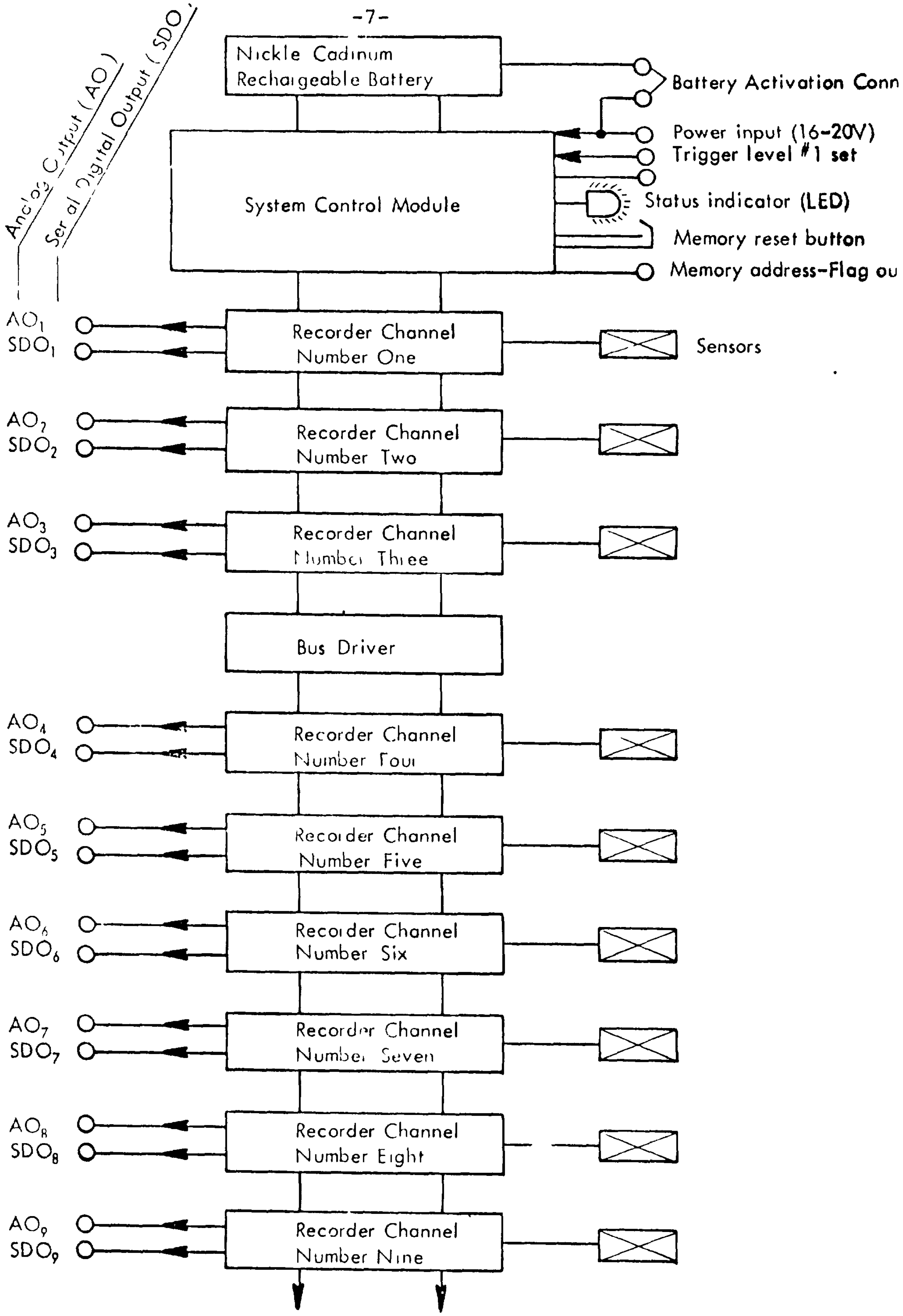


FIGURE 2.0

FUNCTIONAL BLOCK DIAGRAM OF VEHICLE CRASH RECORDER

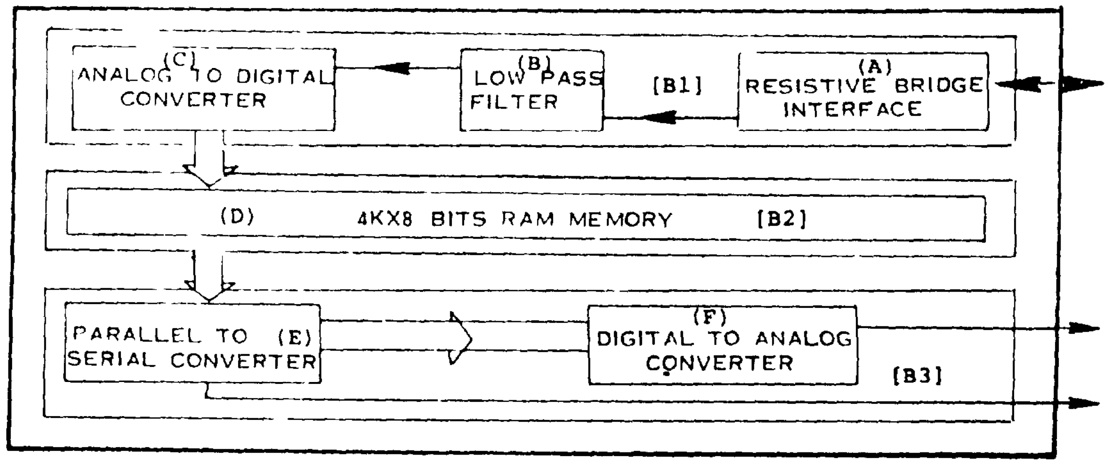


FIGURE 2.1

BLOCK DIAGRAM OF RECORDER FUNCTIONS CONTAINED WITHIN EACH SINGLE CHANNEL MODULE SHOWN IN FIGURE 2.0

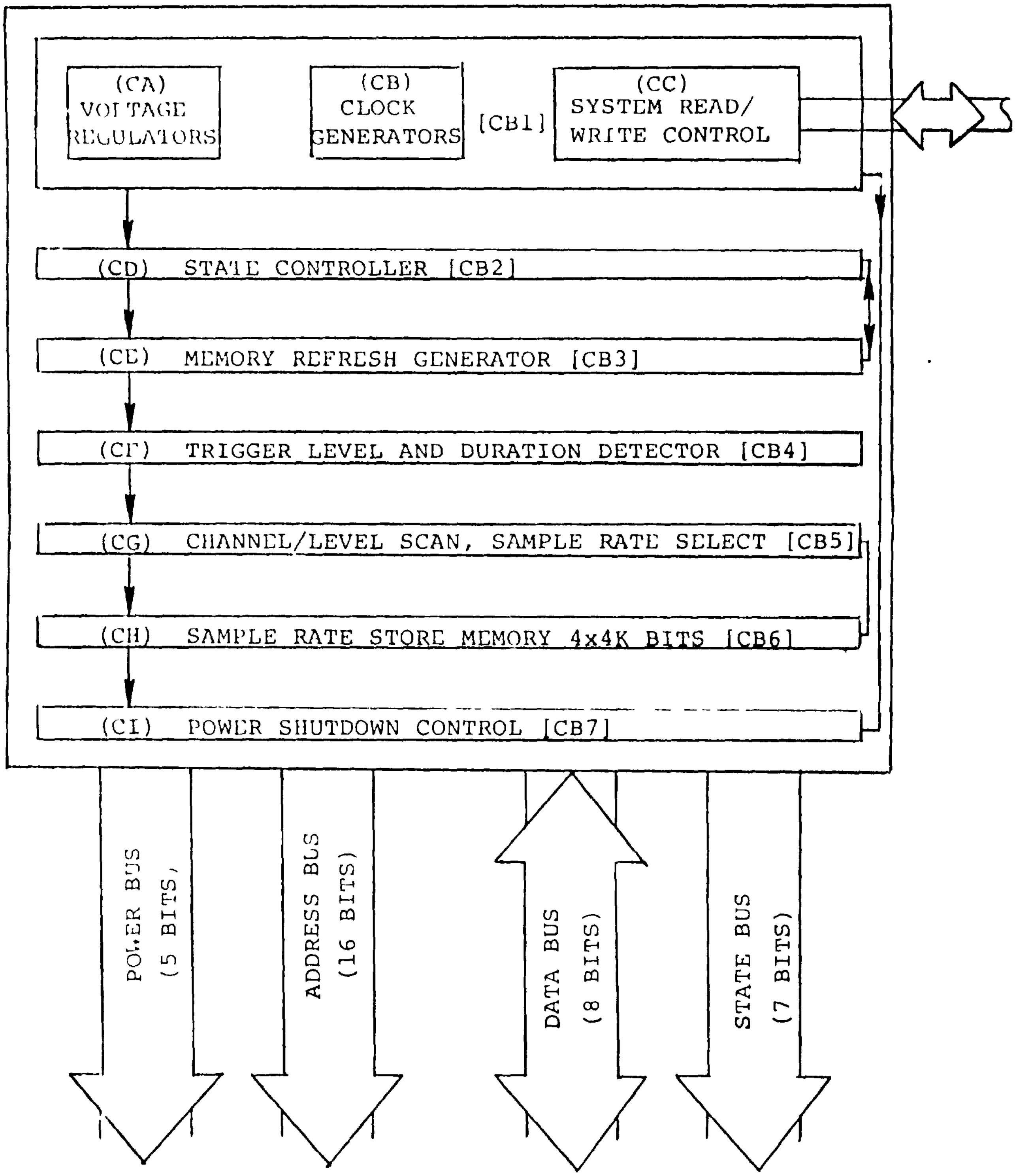


FIGURE 2.2 BLOCK DIAGRAM OF RECORDER FUNCTIONS CONTAINED WITHIN THE BUS CONTROL MODULE

Block (CC) generates the required read/write commands to determine system data flow. Block (CD) monitors the 8 bit data bus to determine if the preset trigger level has been exceeded and, if so, initiates the data store mode sequence. Block (CE) is the state controller which provides the state bus with information defining the operations which the passive recorder modules are to perform. The state controller executes four instructions to each recorder module every 100 microseconds. The four instructions are:

1) Read data from A/D converter into memory if recorder is in read mode; if not, no operation.

2) Start A/D conversion process (which takes 60 μsec to convert one analog sample to digital format).

3) Transfer data from memory to D/A and serial output.

Block (CF) performs the memory refresh function for the dynamic random access memory. Control module Blocks (CG) and (CH) are utilized to control and store analog to digital sample rates which allow the recorder to conserve memory when data is below a settable predetermined threshold. Block (CG) scans the eight channels at an 8 kHz rate to determine which channels have an input which excees the threshold, then depending on which channels are flagged, a sample rate less than or equal to 10 kHz is selected. If no channel exceeds the threshold the recorder goes into an idle mode. Block (CH) is a 4 bit x 4 K storage of the sample rate utilized. This allows reconstruction of the data in real time from stored levels and sample rates.

2.2.1 Hardware Illustration and Definition

Figures 2.3 through 2.6 provide photographs of the nine channel vehicle crash recorder and support equipment.

2.3 System Sensors

The recorder input stages were designed to be general purpose high impedance (1 MΩ) differential preamplifiers which can be interfaced with a variety of sensor types. These include low level voltage inputs, piezoelectric force and acceleration sensors. Precision switched, 10 volt bridge excitation is provided for peizoresistive sensors.

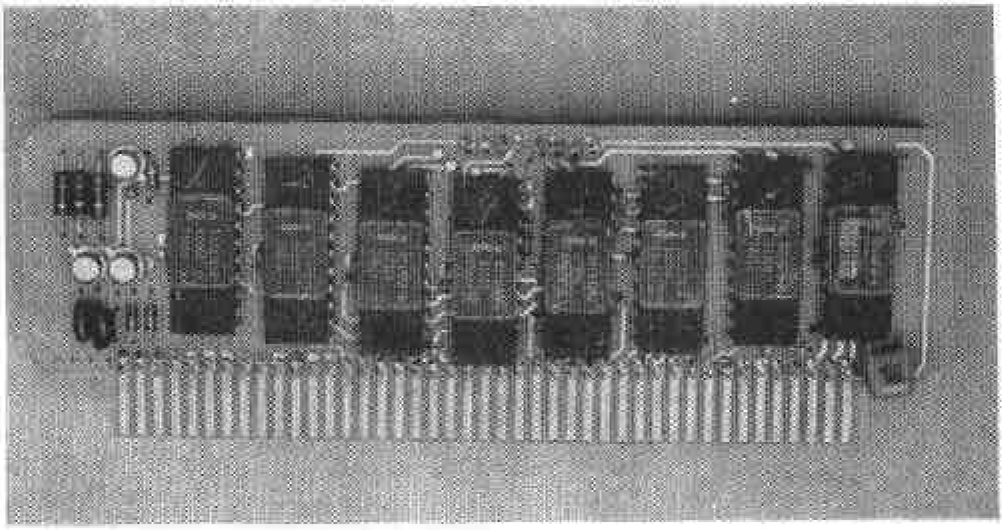
For this preliminary recorder evaluation, ENDEVCO Model 7231C-750 piezoresistive accelerometers were utilized. They are a ±750 g range accelerometer with a sensitivity of .15 to .20 millivolts/g. Figure 2.7 shows a photograph of the three accelerometer and associated cabling utilized during this activity. It might be noted that for the ±100 g environment experienced in vehicle crashes and ±10 g's of rollover events these devices are considerably overranged.

2.4 Recorder Modes

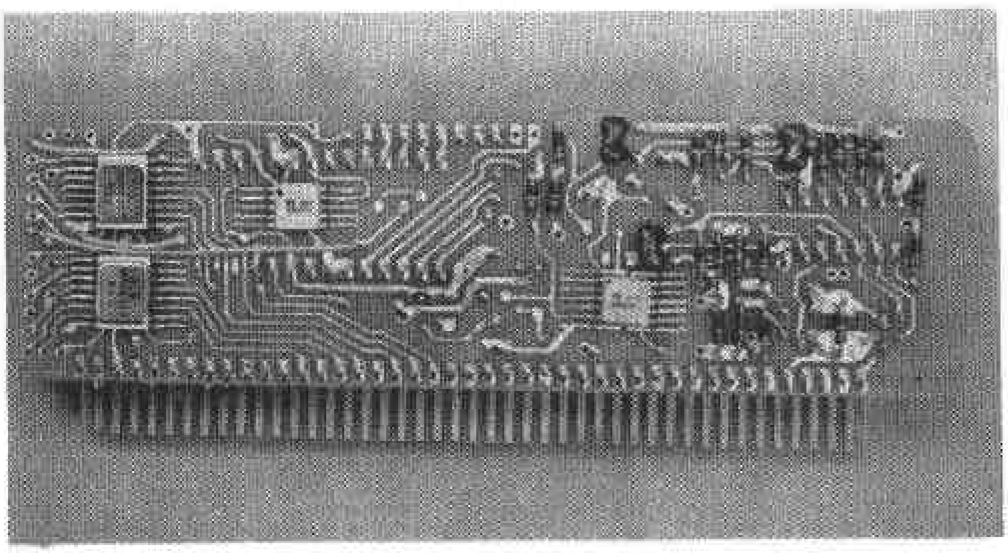
The recorder system has three basic modes of operation which differ greatly in their power consumption. They are:

1. Ready Mode
2. Store Mode
3. Dump Mode

In the ready mode, information is continuously being loaded into memory, and data is simultaneously being monitored by the trigger



A) SIDE
ONE VIEW



B) SIDE
TWO VIEW

FIGURE 2.3 PHOTOGRAPHS OF RECORDER SINGLE CHANNEL ELECTRONICS PACKAGING. PHYSICAL DIMENSIONS ARE 1.25 x 4 x 1 INCHES

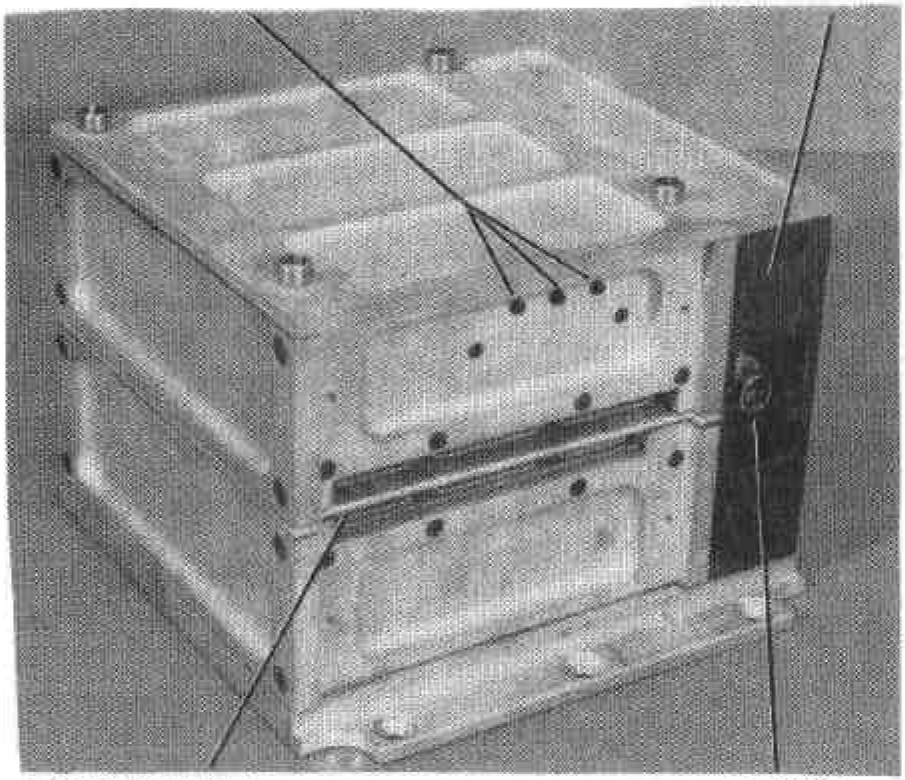
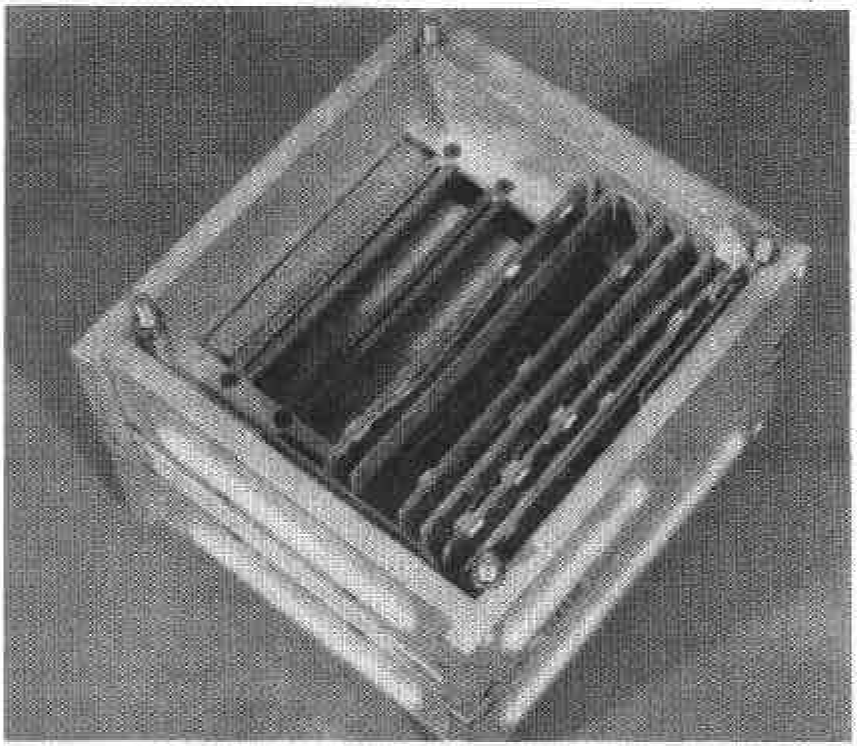
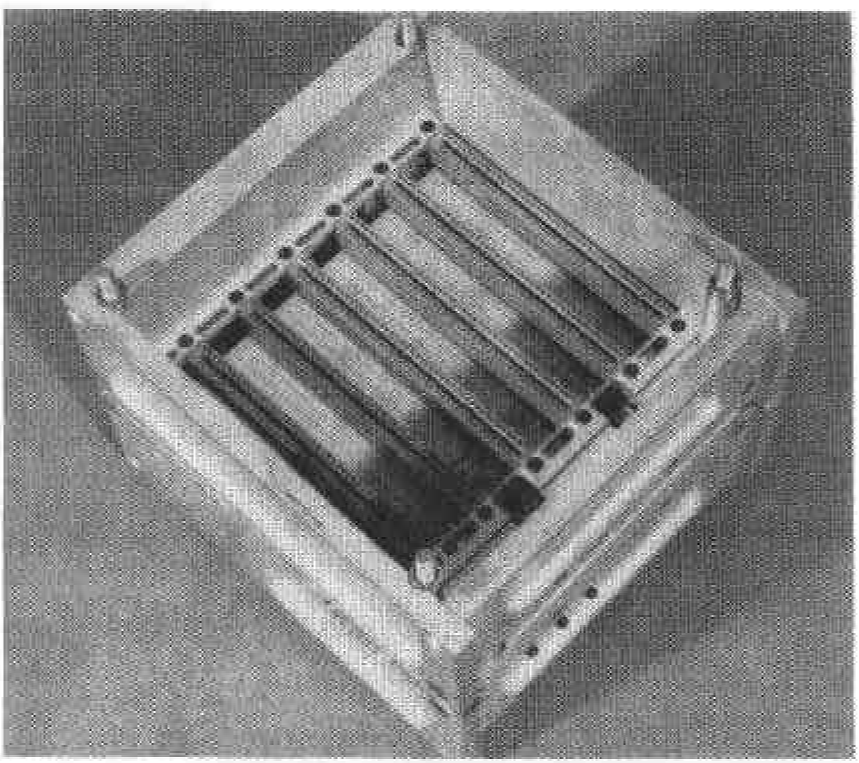


FIGURE 2.4 PHOTOGRAPH OF COMPLETE RECORDER ASSEMBLY



A) TOP VIEW INCLUDING CONTROL MODULE AND CONNECTORS FOR THREE RECORDER CHANNELS



B) BOTTOM VIEW SHOWING CONNECTORS FOR 6 RECORDER CHANNELS

FIGURE 2.5 PHOTOGRAPHS OF RECORDER ASSEMBLY WITH COVER PLATES, RECORDER CHANNEL ELECTRONICS AND BATTERY PACK REMOVED

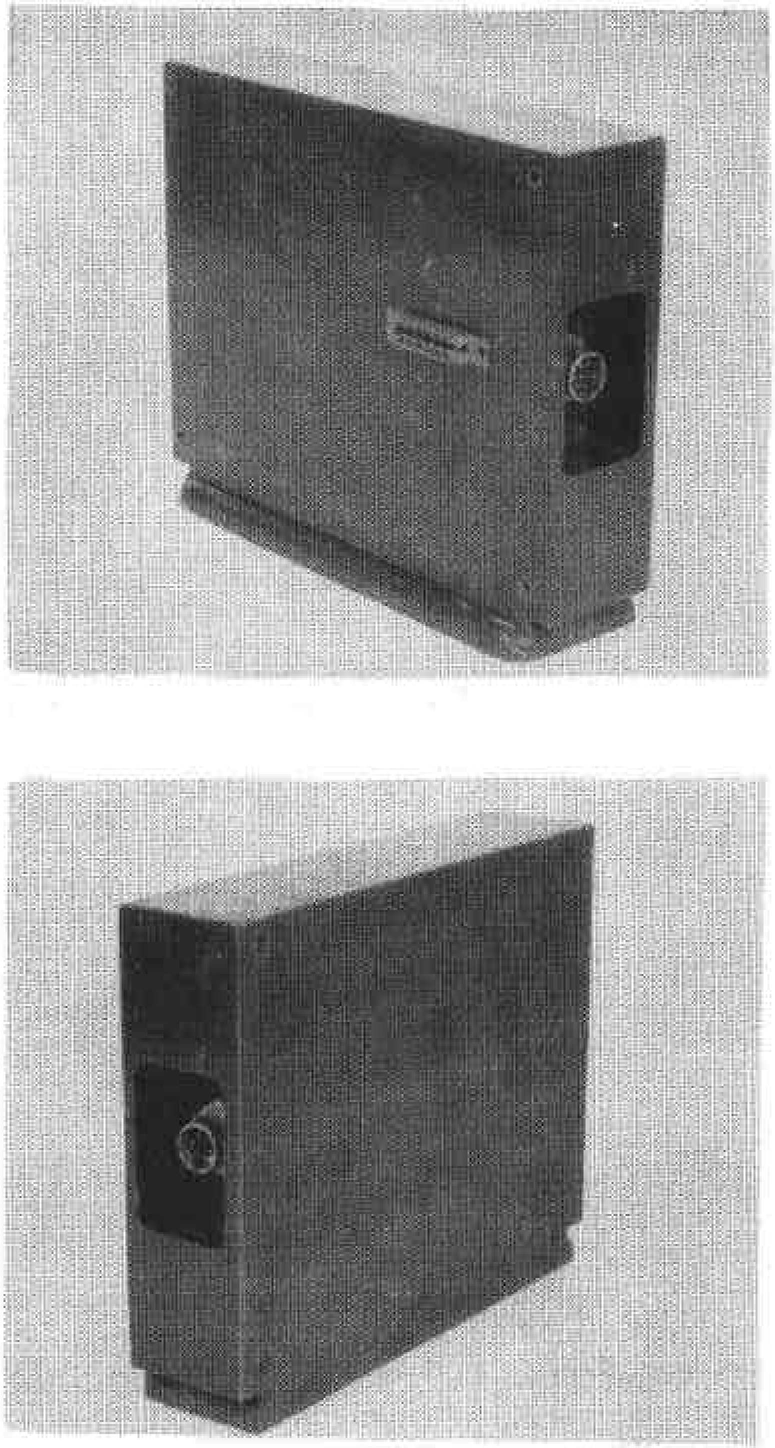


FIGURE 2.6 PHOTOGRAPHS OF RECORDER BATTERY PACK

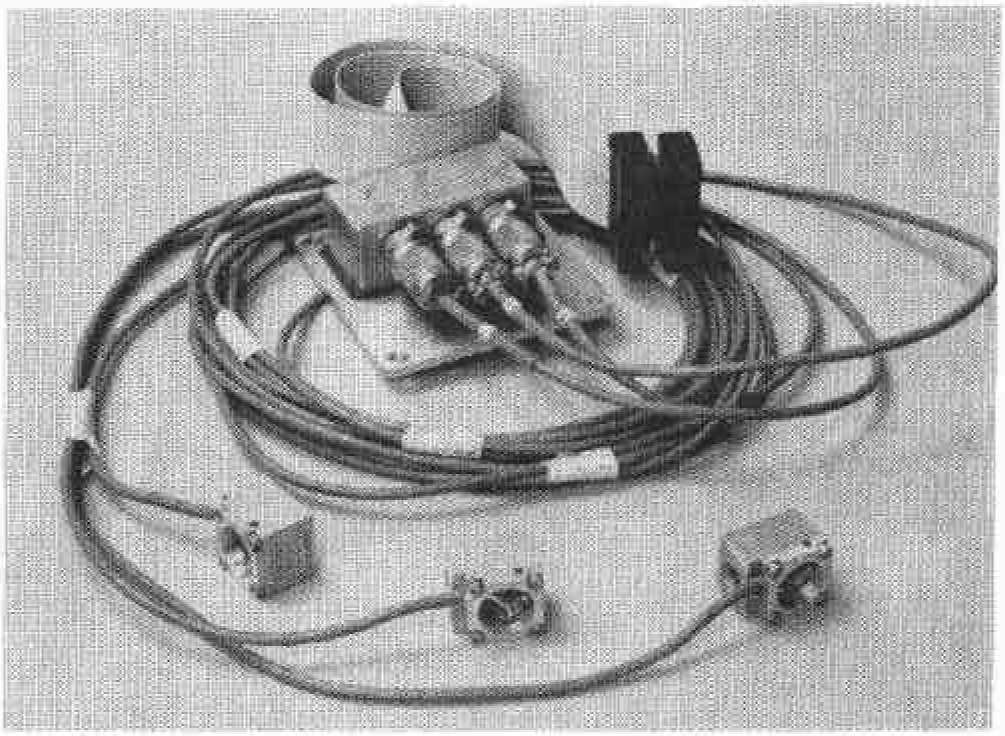


FIGURE 2.7 PHOTOGRAPH OF PIEZORESISTIVE ACCELEROMETERS AND ASSOCIATED CABLING

generator. This is a high power consumption mode and is indicated by light emitting diodes (LED's) located on the front of the recorder. The ready mode is entered into by inserting the reset plug into the recorder pushing the reset button. The store mode is a lower power state in which memory refresh is the only function being performed, power to the piezoresistive sensors is turned off. This mode is automatically entered into when the triggering sequence is completed. The third mode is a data dump which is utilized in extracting data from the recorder memory. This is also a high power mode of operation. Due to the different power consumption in the various modes of operation, system store time is a function of how long the recorder is in each mode. If the battery pack is fully charged, the recorder operation vs time is shown in Figure 2.9. This illustrates the data store time as a function of time which it is in the ready mode (i.e., ready LED is on).

2.5 Triggering Modes

The control module of the recorder system has several triggering modes which can be arbitrarily selected. The first mode is an internal trigger in which the digital outputs of the A/D converters of any three (preselected) channels are continuously monitored and compared to a preset value. The second trigger mode is also an internal trigger and applies to any single preselected channel, and it requires that a preset level be exceeded for some given time interval. The third possible trigger mode is the input of an external pulse to the control module to initiate the triggering sequence. This input pulse could come from a number of different external sources such as a remote impact switch on the front bumper of the

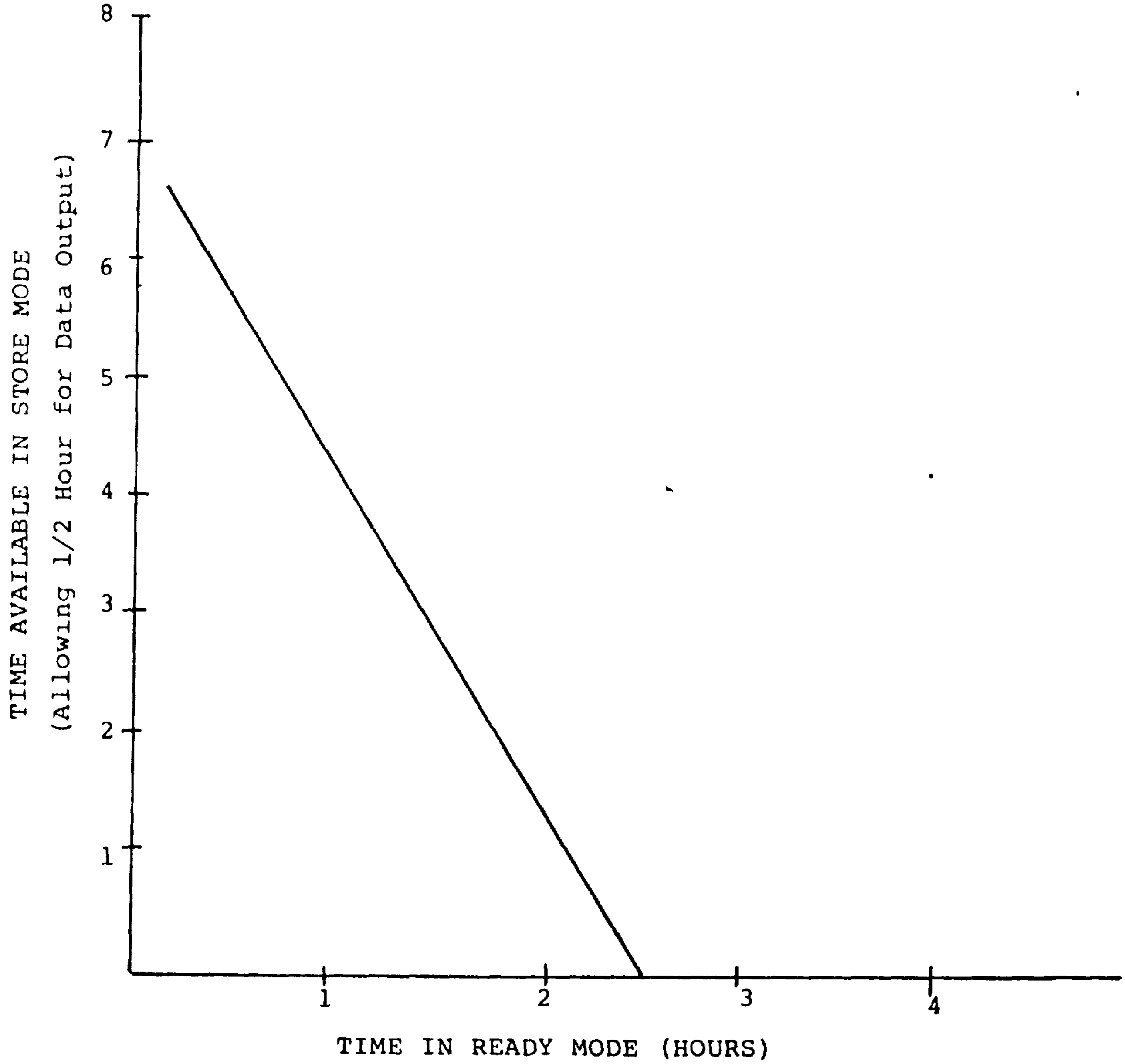


FIGURE 2.8

Illustration of Recorder Store Time as a Function of Time Spent in the "Ready Mode" Assuming a Fully Charged Battery Pack and Allowing 1/2 Hour for Read Out of Data.

vehicle, a pulse generated when photographic coverage of the event begins, or the trigger output generated by a recorder in another anthropomorphic dummy. Once the trigger is initiated, the remaining three-fourths of the memory is filled with data and the recorder is put in a store mode. This type of triggering is uniquely appropriate for pulse capturing instrumentation and offers several major advantages. When the recorder is put in a "ready mode" with the reset button, the A/D converters are running and the memory is being continuously filled with data. Thus, at any point in time each channel of meory already has in storage the last 4096 words of record. When one of the trigger criteria is met, the next 3064 words of data is loaded in memory and the recorder goes into a store mode. The result is that 1026 words of data prior to the trigger point is stored as well as 3064 words of data after that point. The principal advantage is that the trigger level may be set high for maximum noise immunity while still being able to record the rise up to the trigger point. The location of this trigger point in the memory is a presetable quantity and can be changed per the desired application.

2.6 Data Read Out

Once the recorder has captured the acceleration data as indicated by the status of the light emitting diodes (i.e., LED's are out), information is extracted from the recorder via the readout connectors and cabling shown in Figure 2.8. This is accomplished by plugging the read out cable into the crash recorder. Analog data is then output on the BNC connectors of the read out cable when the DATA-OUT switches are activated.

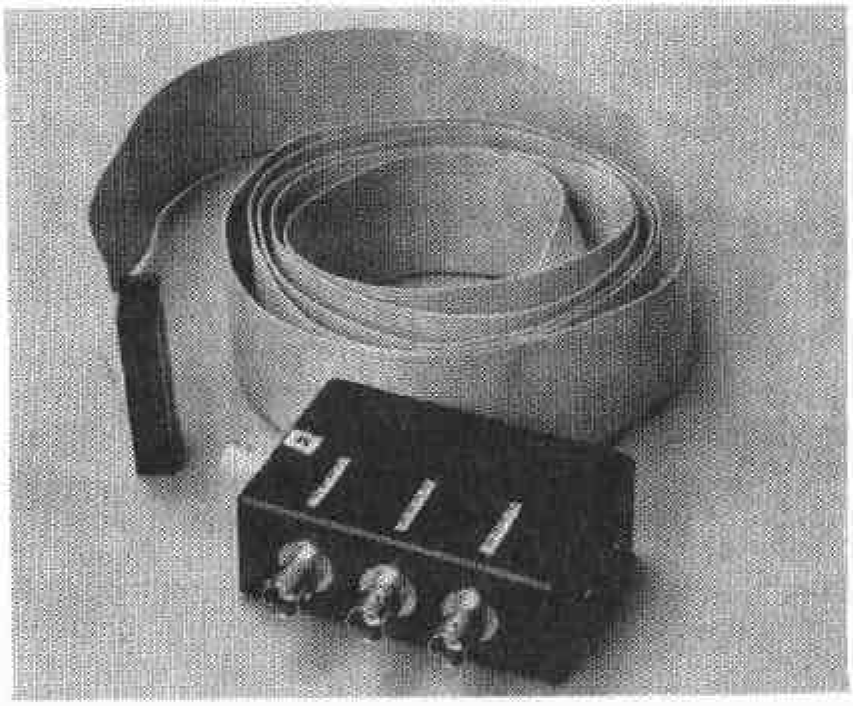


FIGURE 2.9 PHOTOGRAPH OF THE VEHICLE CRASH RECORDER DATA READ OUT CABLE

Provision has also been made for relating the analog data output to its location in memory and trigger point. This is output through the read-out box via the BNC connector labeled "Memory Flag" (MF). The system trigger point corresponds to one-fourth point between the positive going edges of the MF pulses.

2.7 Status Indicators

The status of the recorder system as to whether it is in a ready, triggered, or store mode is indicated by light emitting diodes which are mounted on the front of the recorder. If the ready light is <u>on</u> the recorder channel is in "ready" status and waiting for a trigger command (either internally or externally). When the trigger light goes on it indicates that the trigger pulse has been received and the recorder is about to go into the store mode. If data are read from memory the ready status is unaffected.

2.8 Field Operating Procedure

A typical field measurement with an on board crash recorder in an automotive crash environment, involves the following basic steps by facility personnel:

1) Check that battery pack is fully charged.

2) Mount recorder securely in the vehicle and activate battery pack.

3) Check that ready light (LED) located on the front panel is "on".

4) Execute the vehicle collision.

5) Recover the crash recorder. Ready lights should be out, indicating that the recorder has triggered and is now in the store mode.

6) Extract data from recorder memory and display as desired.

7) Inspect for damage to the recorder, check functional operation, repair if required.

8) Connect battery to charger (data will be retained as long as power is supplied to the recorder).

9) Ready for next test.

3.0 SYSTEM TEST AND EVALUATION

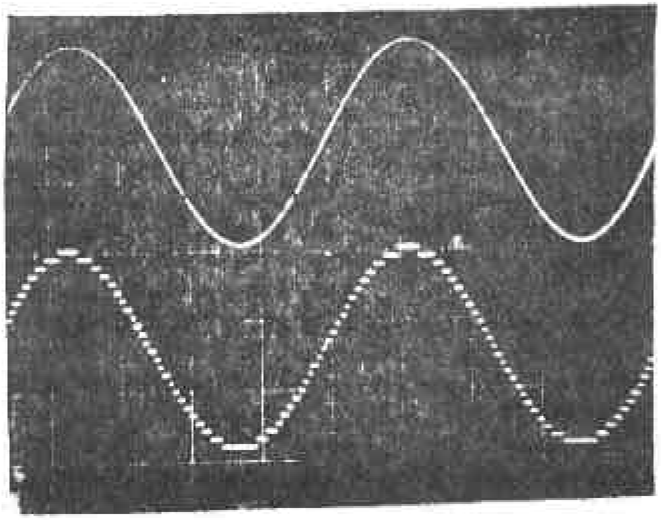
Test and evaluation of the vehicle crash recorder was done via electronic simulation, vibrational testing at the 60 g level, shock machine testing at the 200 g level, and actual vehicle barrier and rollover tests. Each of these test series are described in detail in the following sections.

3.1 Electronic Simulation

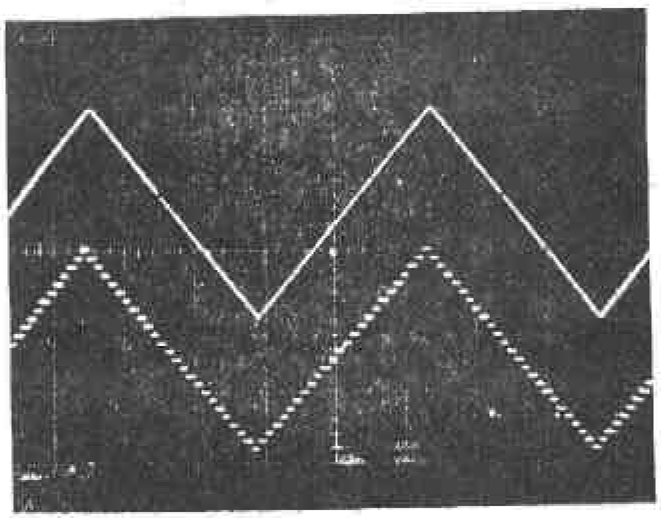
Recorder system fidelity was verified by superimposing analog input signals across accelerometer bridge networks. This was done by insertion of a calibration cable between each accelerometer and the recorder which capacitively coupled an external function generator to the input circuits of the recorder. The corresponding input and output signals were then compared in detail to verify system gain, frequency response, and pulse shape preservation in general. Figures 3.1 and 3.2 compare typical analog input and the corresponding output waveforms.

3.2 Vibration Testing

The vehicle crash recorder complete with all nine channels, battery pack, and accelerometers was vibration tested on a LING shaker. Figure 3.3 shows the mounting of the recorder on the shaker table in the three axes tested. During all vibration testing the recorder was turned on and operating under battery power. Three accelerometers were connected to the inputs of the recorder which were mounted on the shaker table and oriented so as to monitor table and recorder acceleration. The output of the recorder was then monitored and compared to a control accelerometer mounted on the table. The location and orientation of these accelerometers is shown in Figure 3.3.

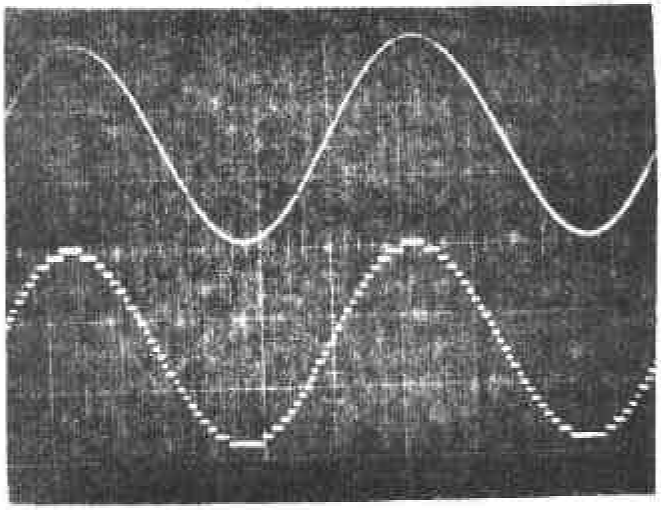


Sine wave, upper trace is input signal and lower trace is recorder output (unfiltered).

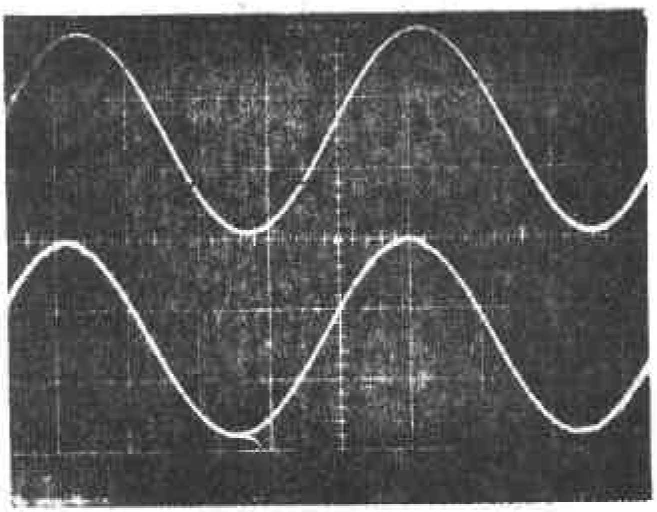


Triangular wave, upper trace is input signal and lower trace is recorder output (unfiltered)

FIGURE 3.1. OSCILLOSCOPE TRACES OF ANALOG SIGNALS INPUT TO THE RECORDER AND THOSE OUTPUT AFTER A COMPLETE RECORDER CYCLE (TIME BASE 1 ms/div)



Sine wave, upper trace is input signal and lower trace is unfiltered recorder output.



Sine wave, upper trace is input signal and lower trace is filtered output.

FIGURE 3.2. OSCILLOSCOPE TRACE OF ANALOG SIGNAL INPUT TO THE RECORDER AND THE CORRESPONDING OUTPUT SIGNAL AFTER A COMPLETE RECORDER CYCLE (TIME BASE 1 ms/div)

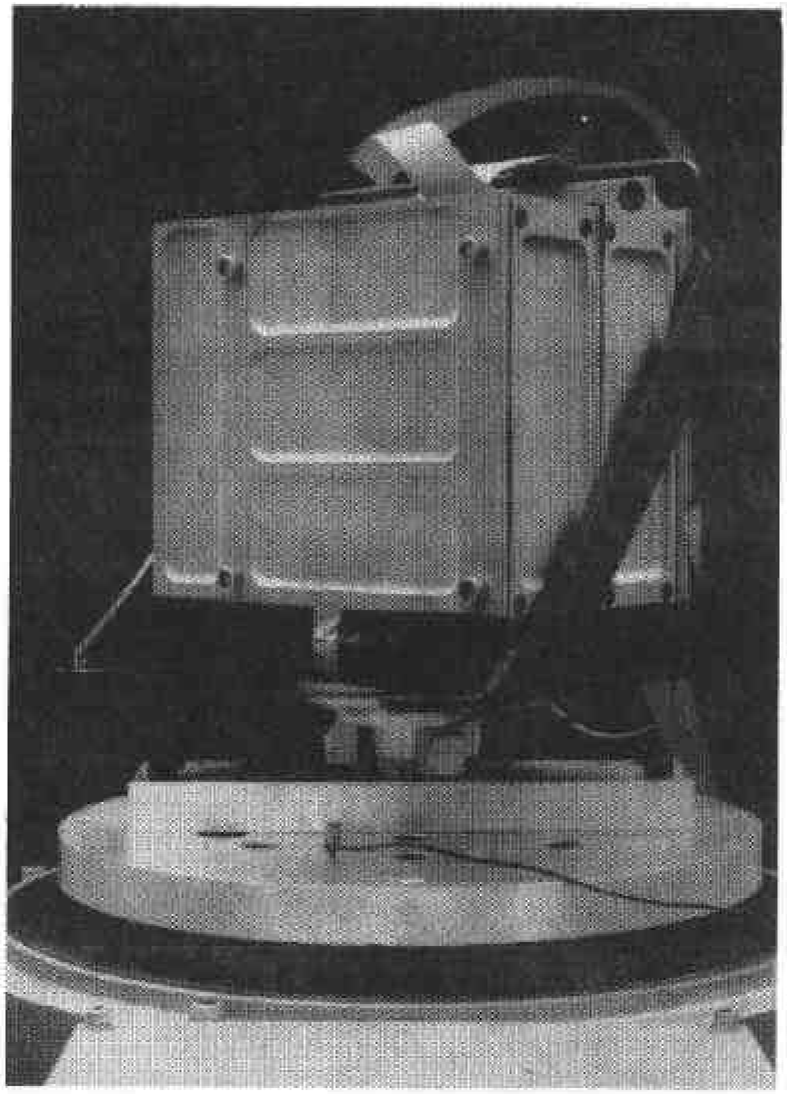


FIGURE 3.3 PHOTOGRAPH OF MOUNTING OF VEHICLE CRASH RECORDER IN X-AXIS ORIENTATION ON ELECTROMAGNETIC SHAKER MACHINE

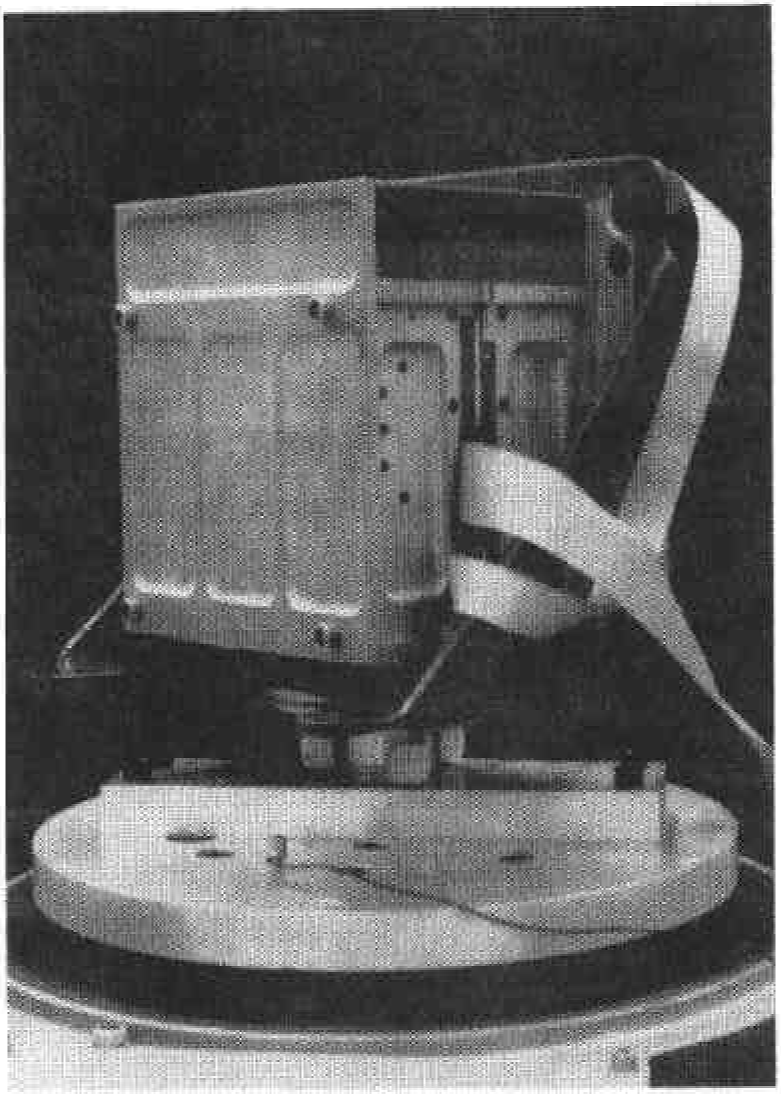


FIGURE 3.3 (Continued) PHOTOGRAPH OF MOUNTING OF VEHICLE CRASH RECORDER IN X-AXIS ORIENTATION ON ELECTROMAGNETIC SHAKER

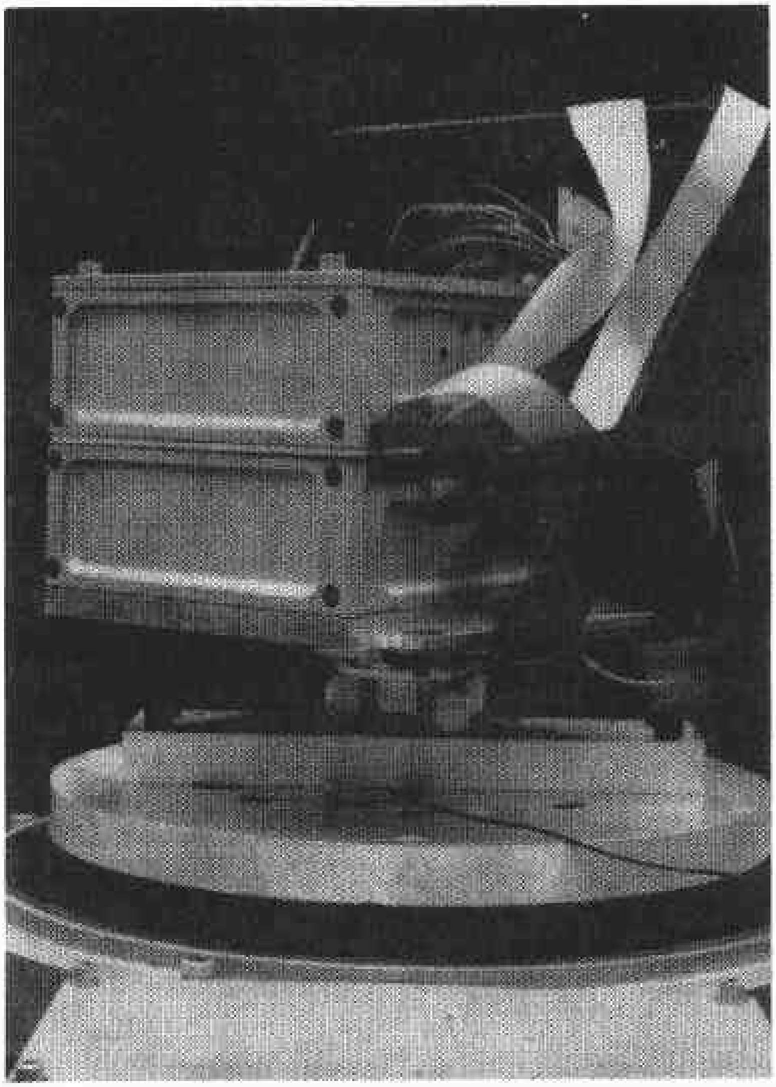


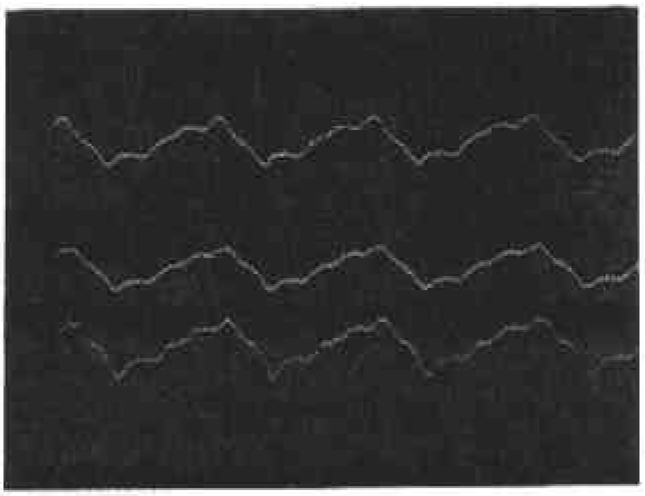
FIGURE 3.3 (Continued) PHOTOGRAPH OF MOUNTING OF VEHICLE CRASH RECORDER IN Z-AXIS ORIENTATION ON ELECTROMAGNETIC SHAKER

The LING shaker has a maximum displacement of one inch, this limitation defines the frequency at which a 60 g acceleration sine wave can be applied to the crash recorder as >35 Hz. Figure 3.4 shows the table acceleration vs time at the 60 g 35 Hz conditions. It should be noted that the applied load is far from a pure sine wave profile. This distortion was investigated by operating the shaker system without the recorder mounted. It was determined that this distortion was being generated within the shaker control system and was not a result of mechanical impedance mismatches due to mounting of the heavy (16.4 lb) crash recorder on a marginally large enough shaker system. Since a non-pure sine wave is usually considered as an overtest no further effort was made to resolve this question.

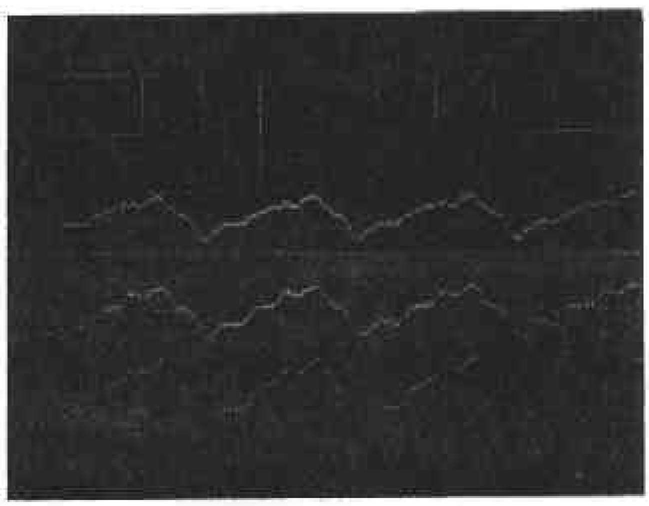
3.3 Shock Machine Testing

The vehicle crash recorder was also evaluated on a single pulse pneumatic shock machine shown in Figure 3.5. The stroke of the device is 2 feet and position velocities of up to 100 miles per hour are achievable. The air accelerated piston is arrested by impact with a pulse shaping medium such as foam rubber which can be configured so as to provide a deceleration pulse of up to several hundred g's for a time duration of greater than ~10 milliseconds (1/2 amplitude). Figure 3.6 show the pneumatic shock machine with the vehicle crash recorder mounted on the piston in the three axes tested.

The recorder was set up so as to trigger externally when piston motion occurred. The recorder therefore monitored acceleration of the piston as well as its deceleration.

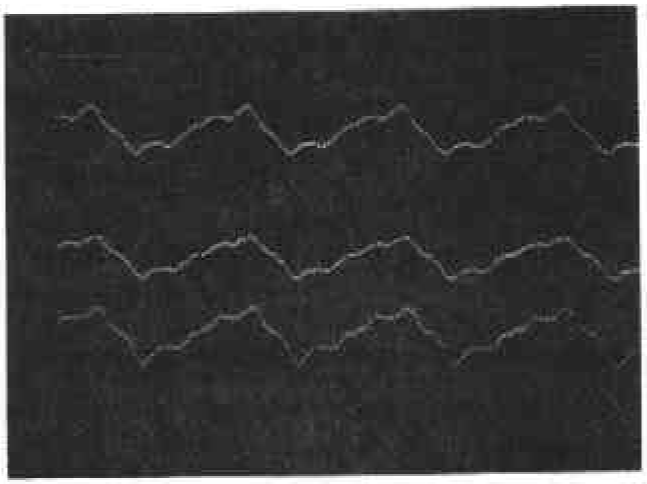


- SHAKER TABLE CONTROL ACCELEROMETER OUTPUT
- RECORDER CHANNEL #1
- RECORDER CHANNEL #2



- RECORDER CHANNEL #1
- RECORDER CHANNEL #2
- RECORDER CHANNEL #3

FIGURE 3.4 ACCELERATION VS TIME AS MONITORED BY THE RECORDER WHILE BEING SUBJECTED TO THE 60 G - 35 HZ VIBRATION ENVIRONMENT ALONG THE X-AXIS. VERTICAL SCALE IS ~50 G/DIV, HORIZONTAL TIME SCALE IS 10 MS/DIV.



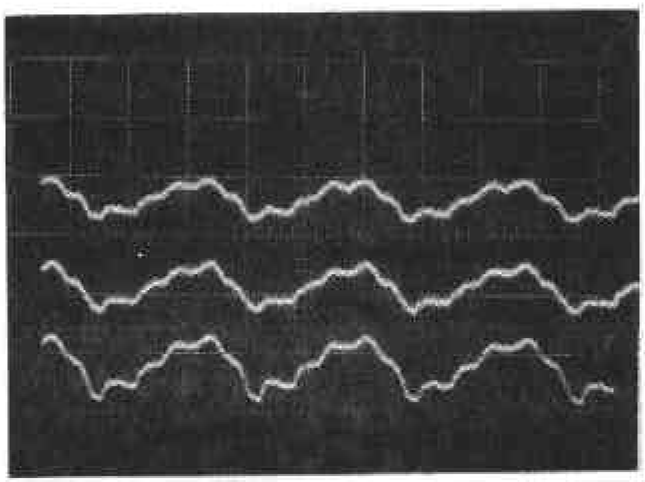
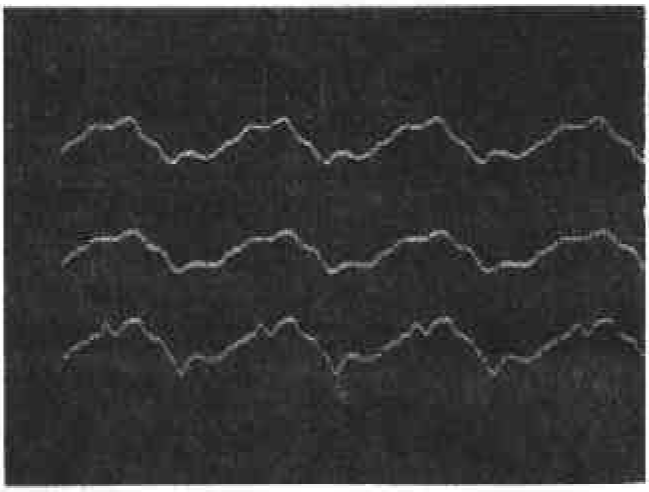
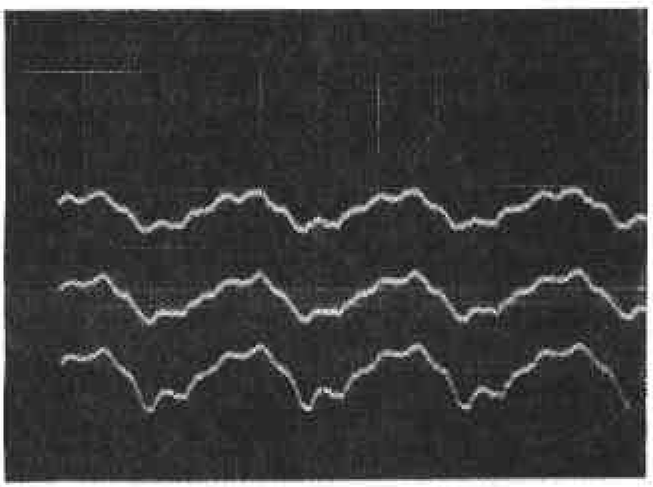


FIGURE 3.4 (Continued) ACCELERATION VS TIME AS MONITORED BY THE RECORDER WHILE BEING SUBJECTED TO THE 60 G - 35 HZ VIBRATION ENVIRONMENT ALONG THE Y-AXIS. VERTICAL SCALE ~50 G/DIV, HORIZONTAL TIME BASE 10 NS/DIV.

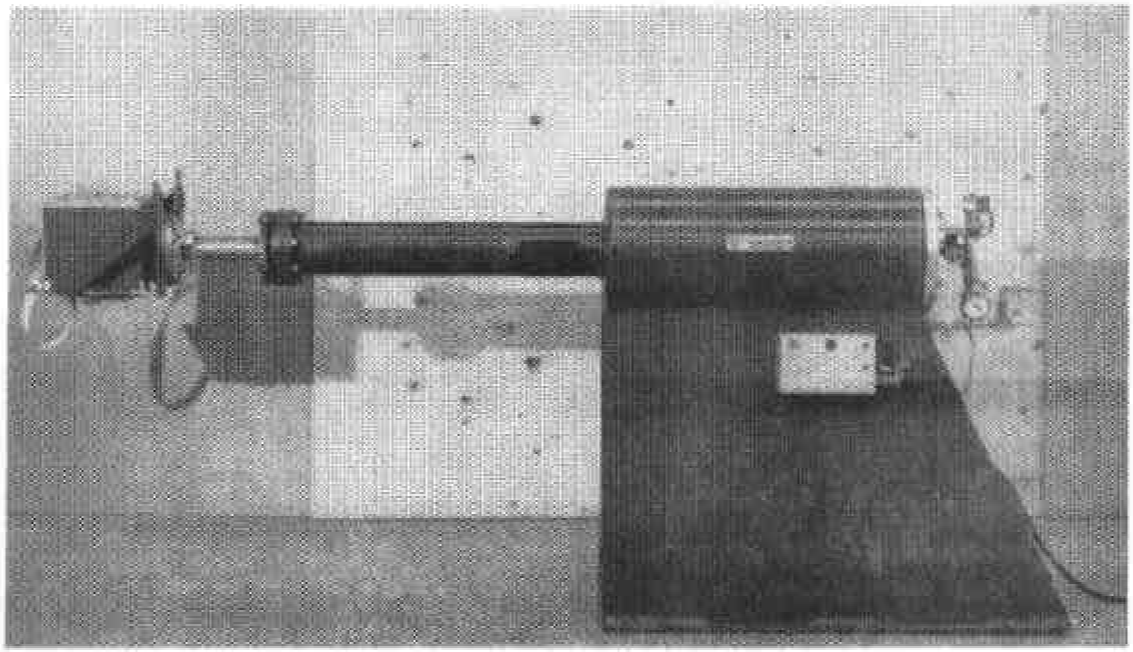


- SHAKER TABLE CONTROL ACCELEROMETER OUTPUT
- RECORDER CHANNEL #1
- RECORDER CHANNEL #2



- RECORDER CHANNEL #1
- RECORDER CHANNEL #2
- RECORDER CHANNEL #3

FIGURE 3.4 (Continued) ACCELERATION VS TIME AS MONITORED BY THE RECORDER WHILE BEING SUBJECTED TO THE 60 G - 35 HZ VIBRATION ENVIRONMENT ALONG THE Z-AXIS VERTICAL SCALE .50 G/DIV, HORIZONTAL TIME BASE 10 MS/DIV.



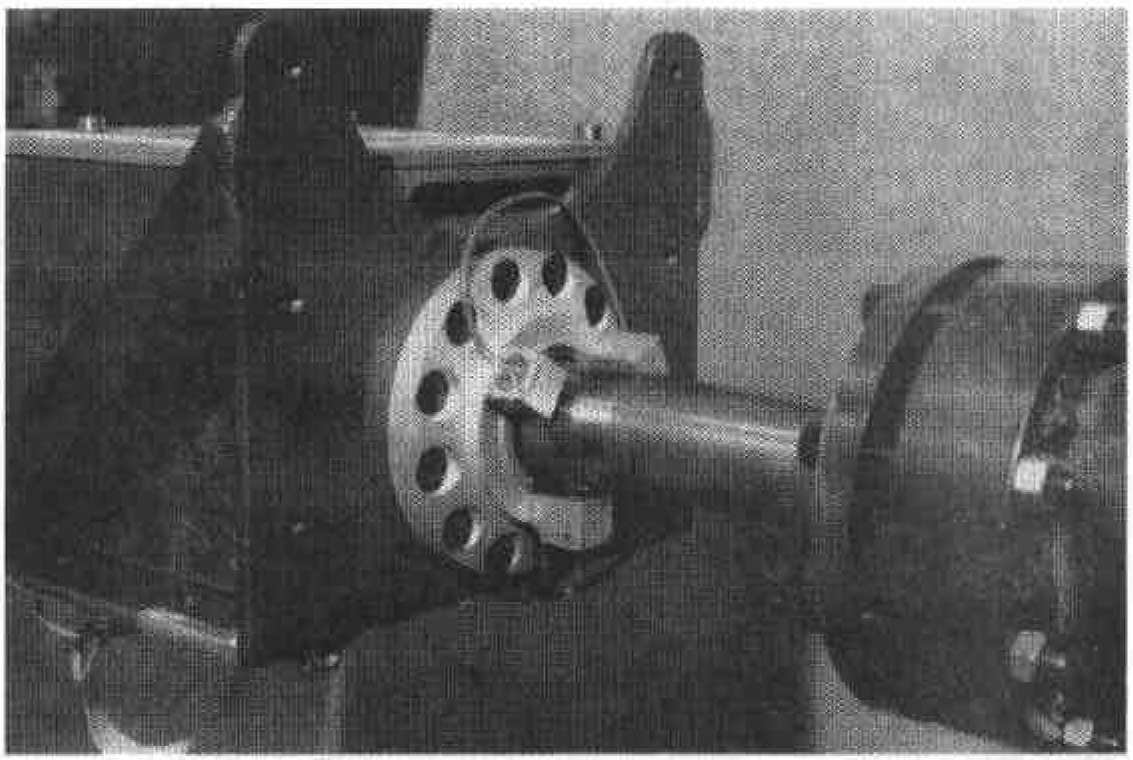
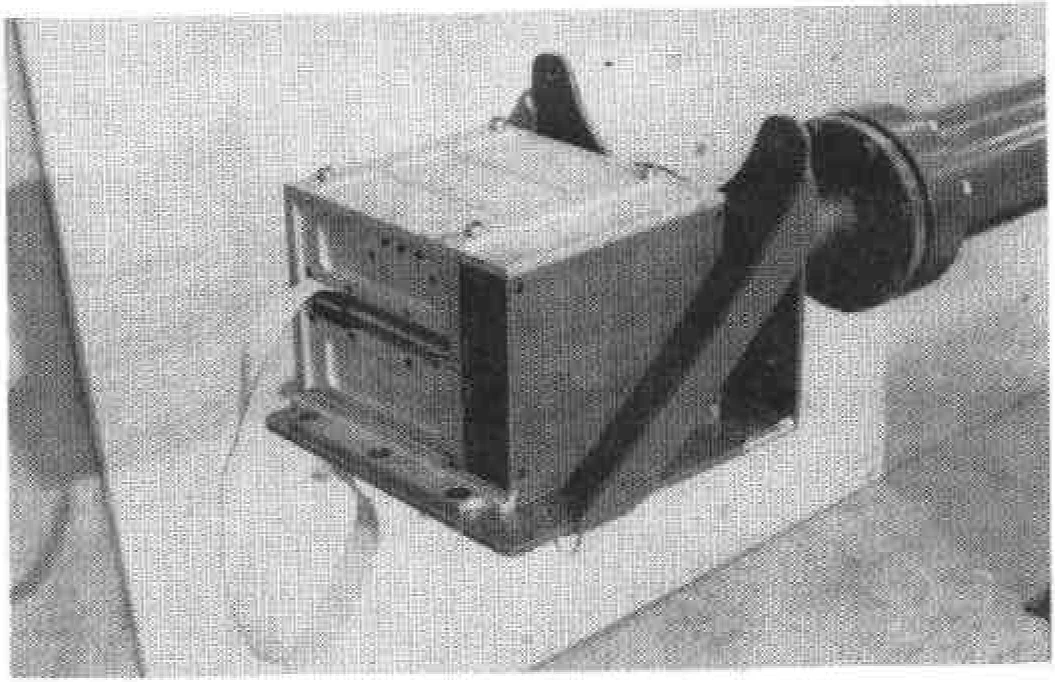


FIGURE 3.5 PHOTOGRAPHS OF THE PNEUMATIC SHOCK MACHINE (UPPER) AND A CLOSE UP PHOTOGRAPH OF THE ACCELEROMETER MOUNTING ON THE PISTON (LOWER)



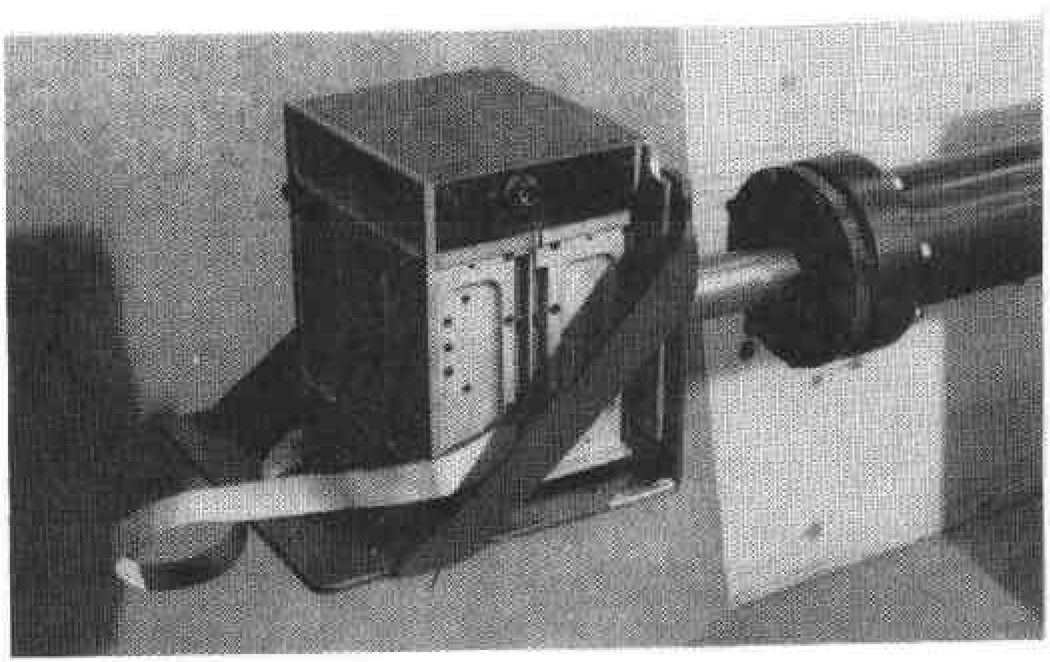


FIGURE 3.6 PHOTOGRAPHS OF TWO OF THE THREE ORIENTATIONS WHICH THE RECORDER WAS MOUNTED ON THE PNEUMATIC SHOCK MACHINE. THE UPPER PHOTOGRAPH CORRESPONDS TO THE X-AXIS LOADING AND LOWER CORRESPONDS TO THE Z-AXIS LOADING.

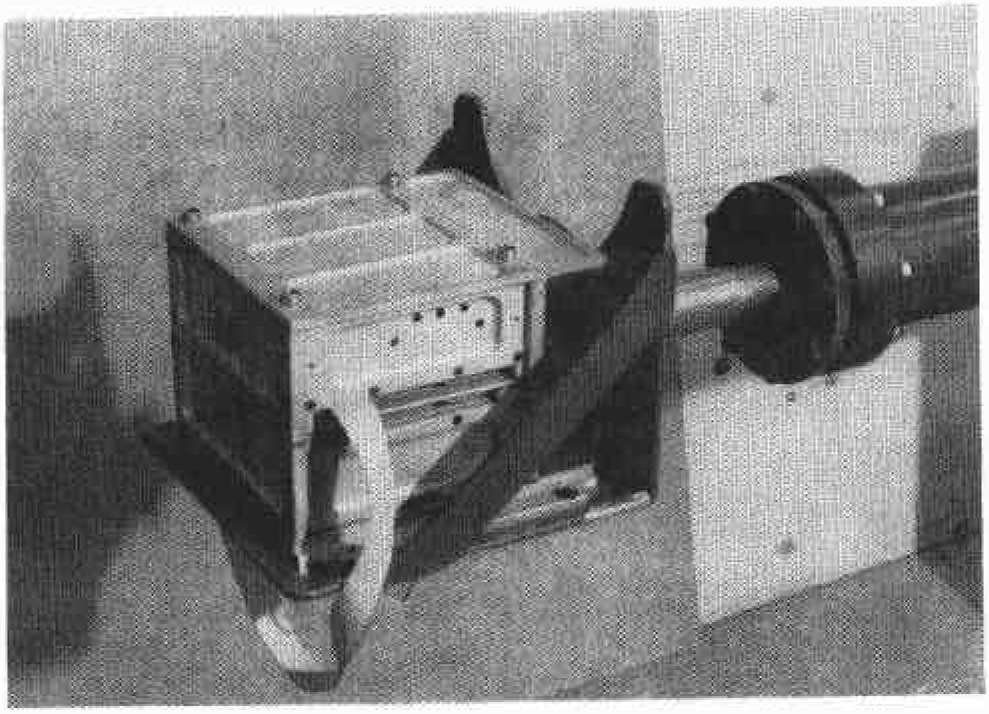
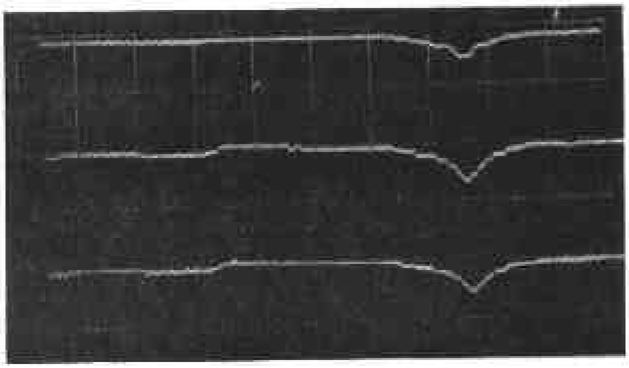
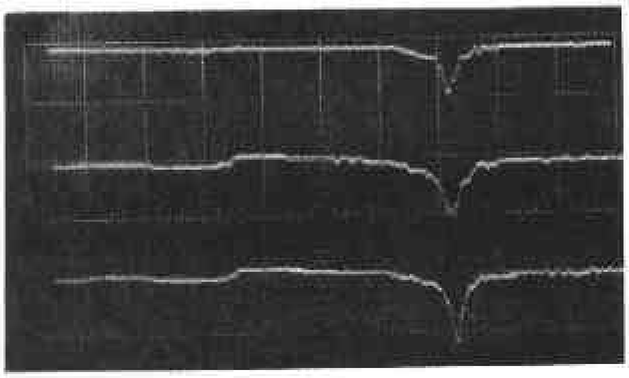


FIGURE 3.6 (Continued) PHOTOGRAPH OF THE THIRD ORIENTATION WHICH THE RECORDER WAS MOUNTED ON THE PNEUMATIC SHOCK MACHINE AND WHICH CORRESPONDS TO THE Y-AXIS.

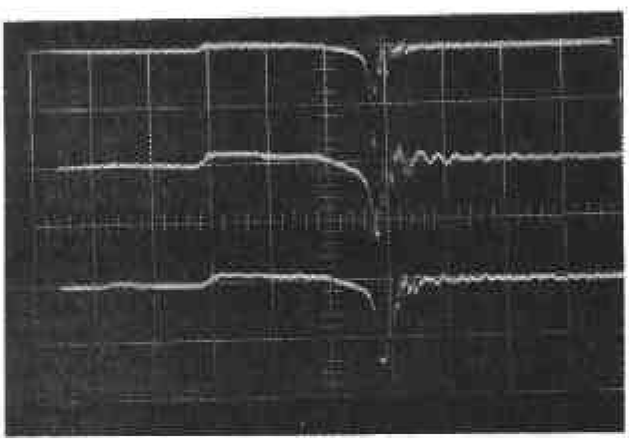
Figure 3.7 shows the acceleration vs time as monitored by the three accelerometer and captured by the recorder during launch and impact for several different piston velocities, the corresponding peak accelerations and pulse widths have been identified.



A) SHOCK MACHINE
CHAMBER PRESSURE
40 PSI

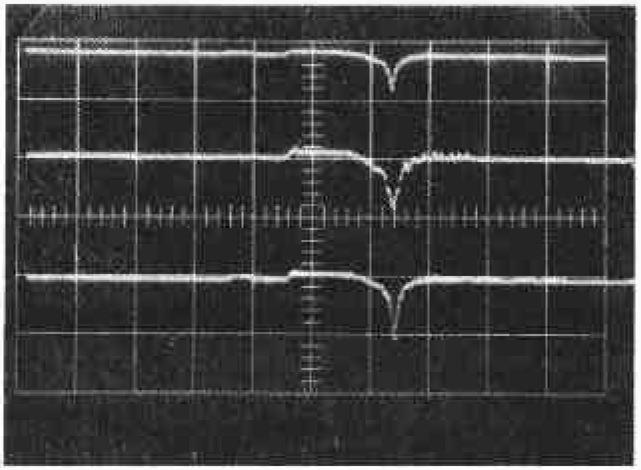


B) SHOCK MACHINE
CHAMBER PRESSURE
50 PSI

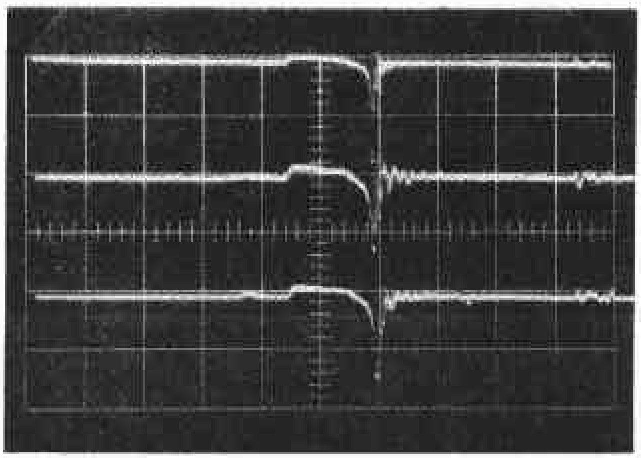


C) SHOCK MACHINE
CHAMBER PRESSURE
60 PSI

FIGURE 3.7 ACCELERATION AND IMPACT TIME HISTORIES AS CAPTURED, STORED AND LATER READ OUT BY THE VEHICLE CRASH RECORDER WHILE BEING SUBJECTED TO THAT SAME ENVIRONMENT. THE POSITIVE GOING PREIMPACT DATA CORRESPONDS TO PISTON ACCELERATION. VERTICAL SCALE IS A 100 G/DIV ON ALL CHANNELS. TIME BASE IS 50 MILLISECONDS/DIV. TRIGGERING WAS DONE BY A BRAKE WIRE CONNECTED BETWEEN THE PRESSURE CHAMBER AND PISTON.



A) SHOCK MACHINE
CHAMBER PRESSURE
50 PSI



B) SHOCK MACHINE
CHAMBER PRESSURE
60 PSI

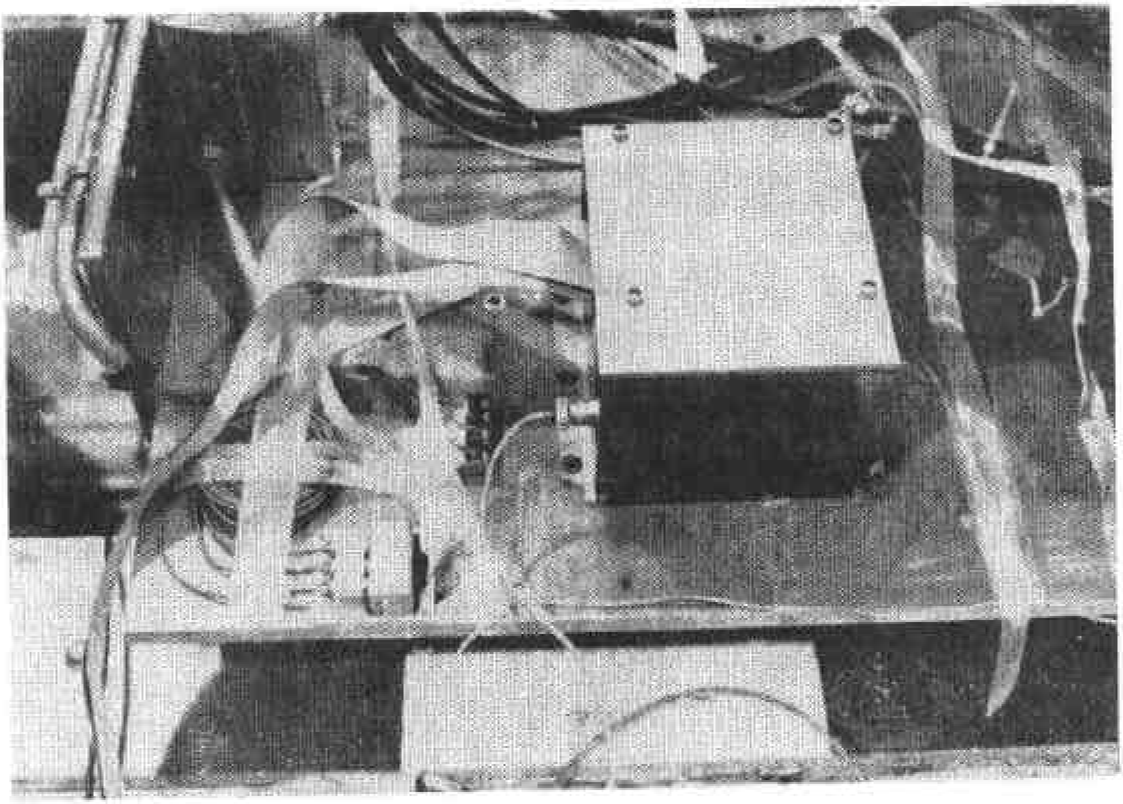
FIGURE 3.7 (Continued) ACCELERATION AND IMPACT TIME HISTORIES AS CAPTURE, STORED, AND LATER READOUT BY THE VEHICLE CRASH RECORDER WHILE BEING SUBJECTED TO THAT SAME ENVIRONMENT. VERTICAL SCALE IS ~100 G PER DIVISION ON ALL CHANNELS. TIME BASE IS 100 MILLISECONDS/DIV. TRIGGERING WAS DONE BY A BRAKE WIRE CONNECTED BETWEEN THE PRESSURE CHAMBER AND PISTON.

3.4 Sled Testing of the Crash Recorder

A sled test series was conducted to evaluate the recorder in a laboratory simulated 30 mph vehicle crash. The series was conducted at NHTSA's Safety Research Laboratory (SRL) in Riverdale, Maryland. The sled is accelerated backwards by a cam and belt arrangement which obtains its energy from a rotating flywheel.

The recorder along with three accelerometers were mounted on the sled floor plate as shown in Figure 3.8. All three accelerometers were oriented so that their sensitive axis were parallel to the sled's track and the primary motion. This is the same orientation as the facilities sled accelerometer which provided the primary data for comparison.

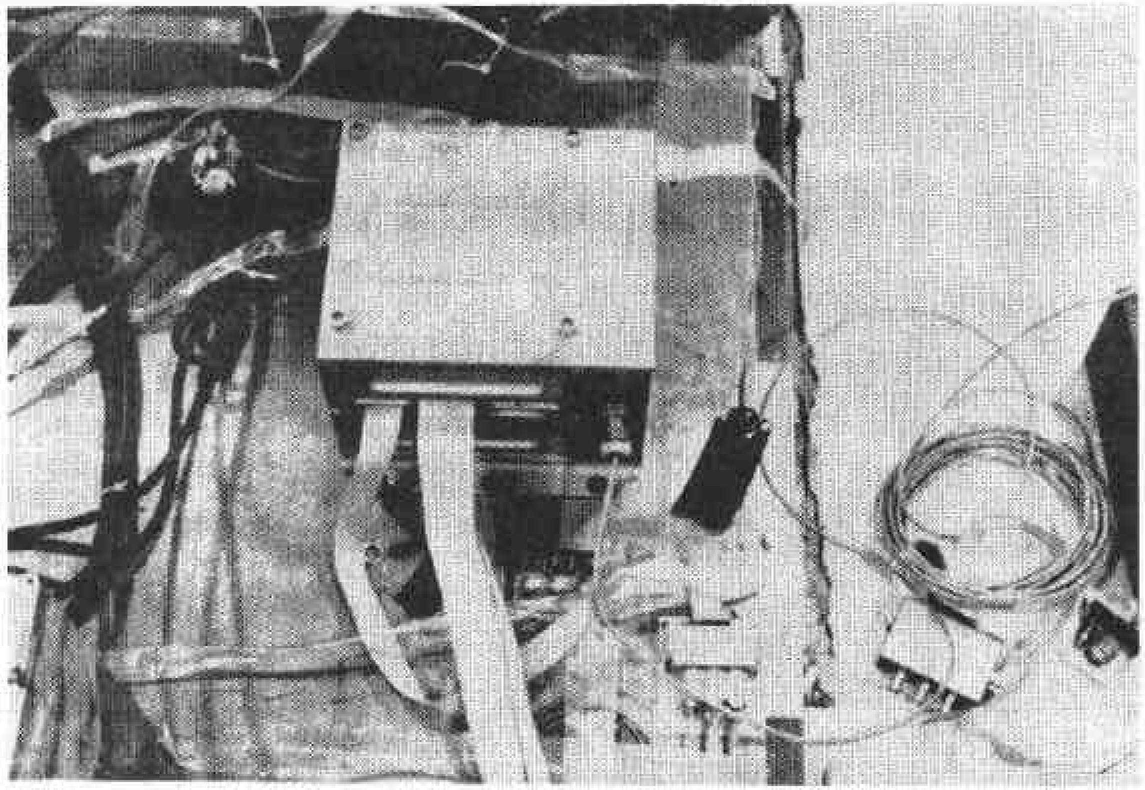
A total of seven sled runs were made. The first three were associated with facility and instrumentation check out and were done at low velocities. Data was not recorded for detailed analysis. Sled test data is provided by the packet of Figure 3.9 which shows the individual acceleration-time histories as monitored by the facility's sled accelerometer and by the three channels of the vehicle crash recorder. The over-layed data of channels 1, 2 and 3 of the vehicle crash recorder and that obtained by facility instrumentation for sled runs numbered 004, 005, 006 and 007 are shown in Figures 3.10, 3.11, 3.12 and 3.13 respectively.



(SIDE VIEW)

FIGURE 3.8

PHOTOGRAPH OF VEHICLE CRASH RECORDER
AND ACCELEROMETERS MOUNTED ON SRL'S SLED



(REAR VIEW)

FIGURE 3.8 (Continued)

PHOTOGRAPH OF VEHICLE CRASH RECORDER
AND ACCELEROMETER MOUNTED ON SRL'S SLED

FIGURE 3.9

MEASURED ACCELERATION - TIME HISTORIES

OF RECORDER SLED TESTING

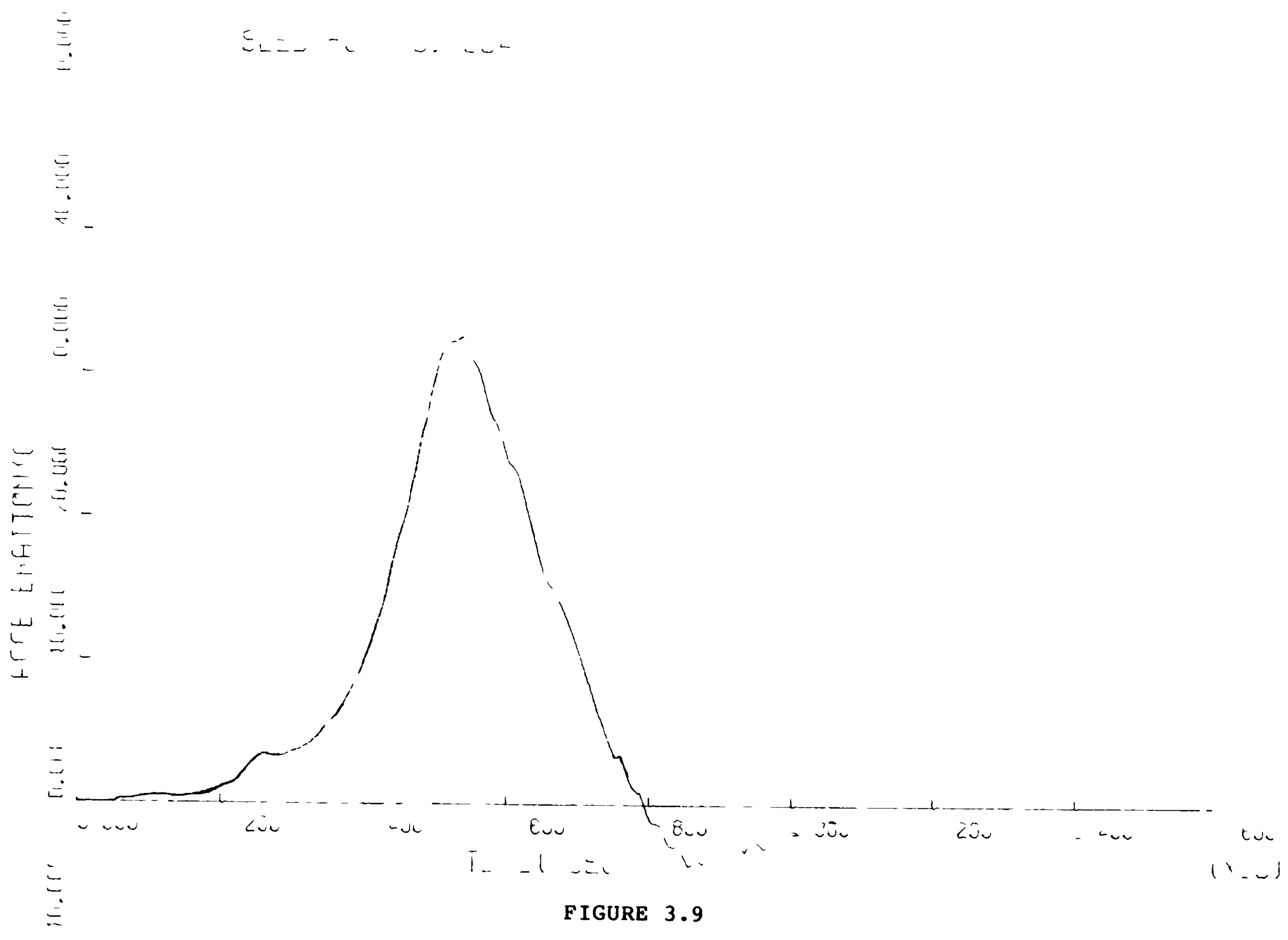


FIGURE 3.9

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

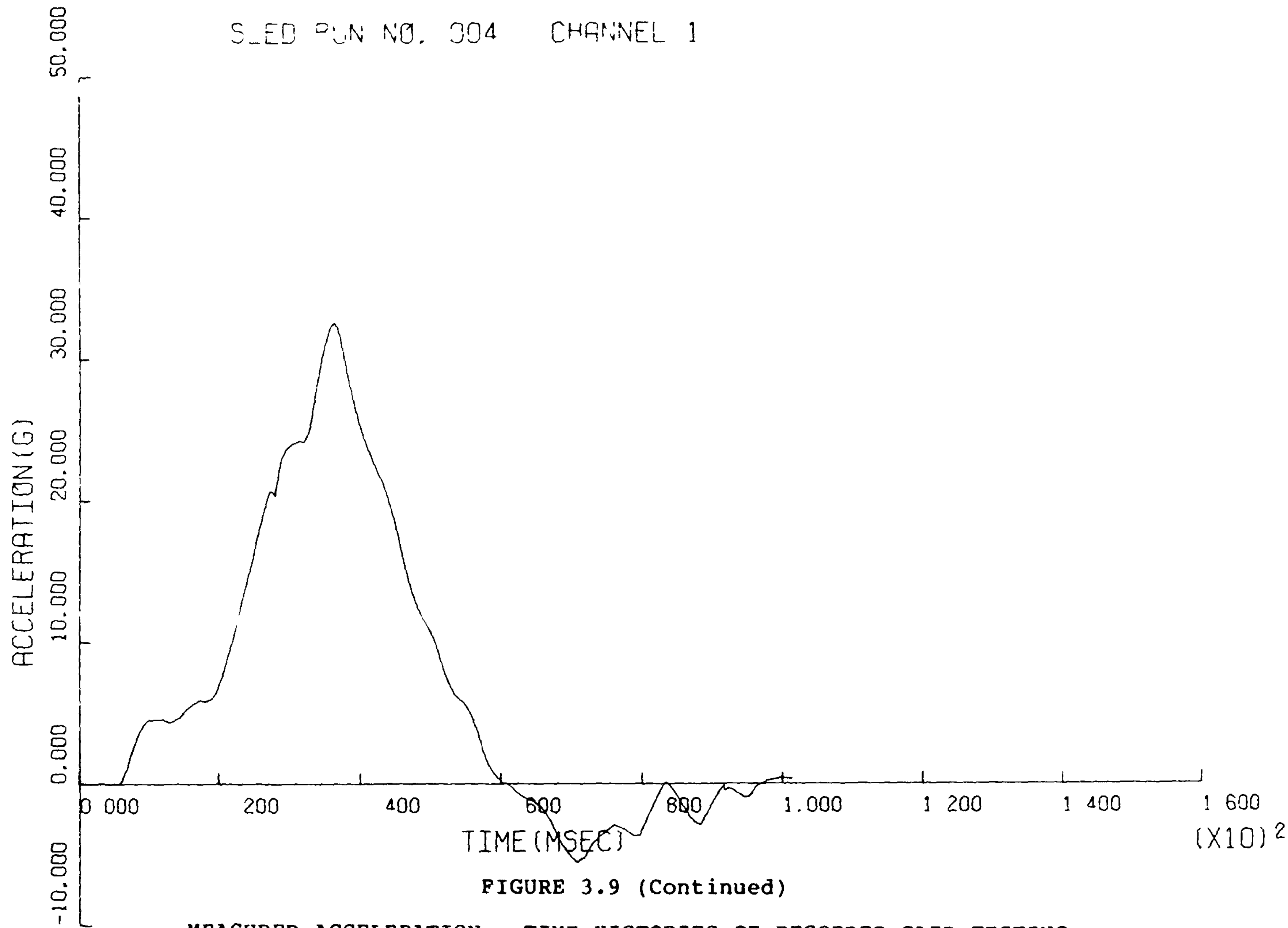


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

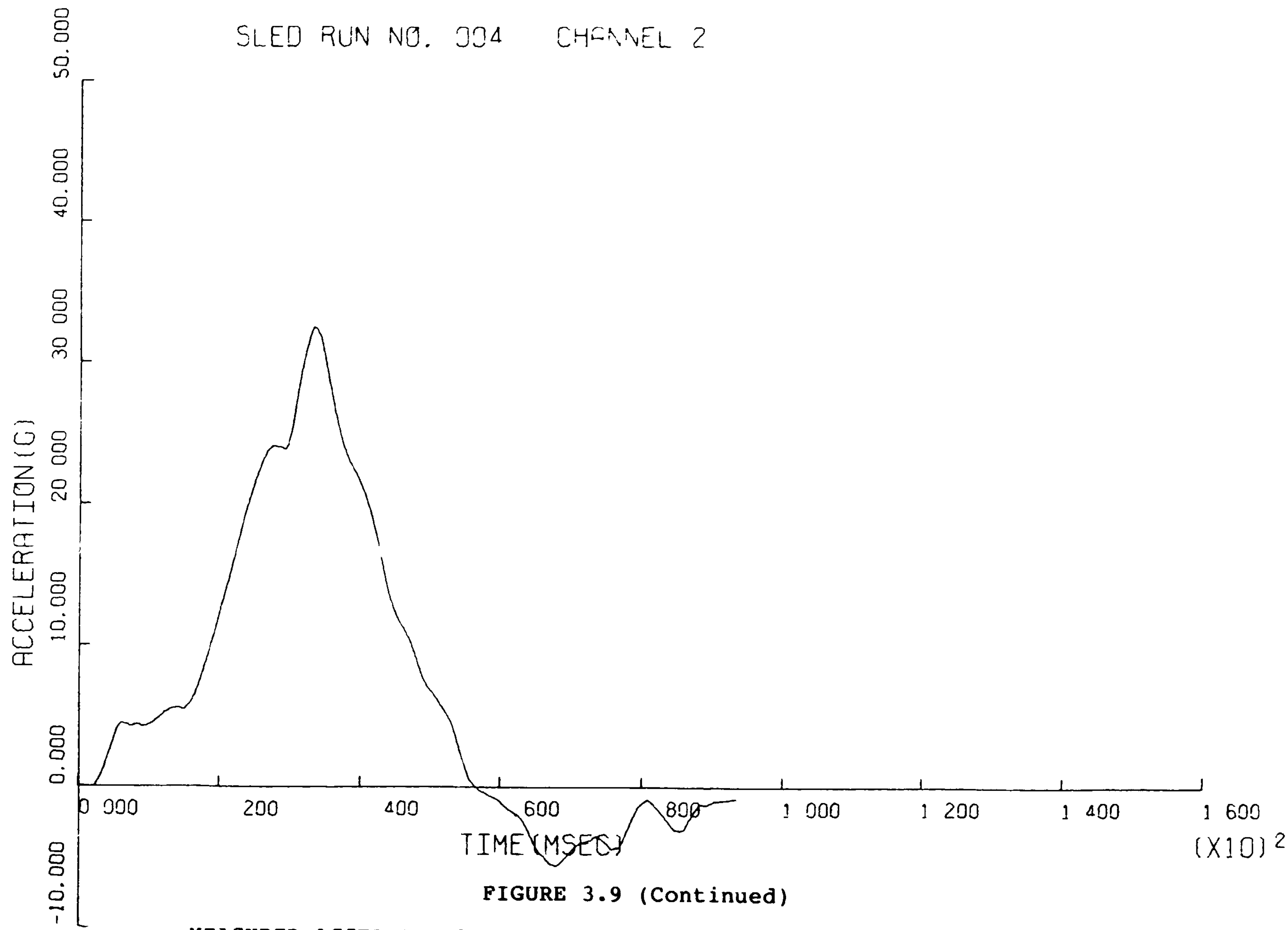


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

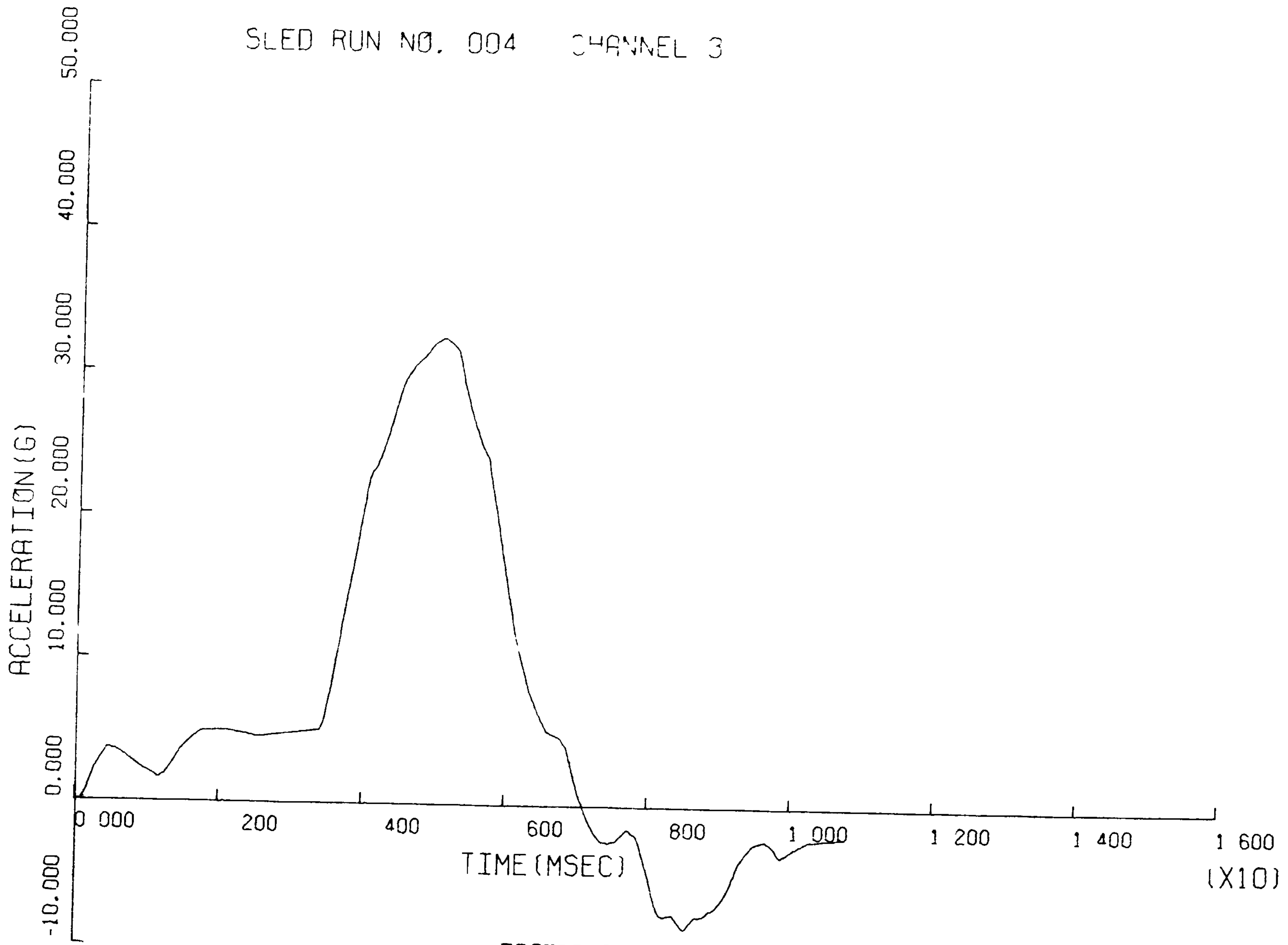


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

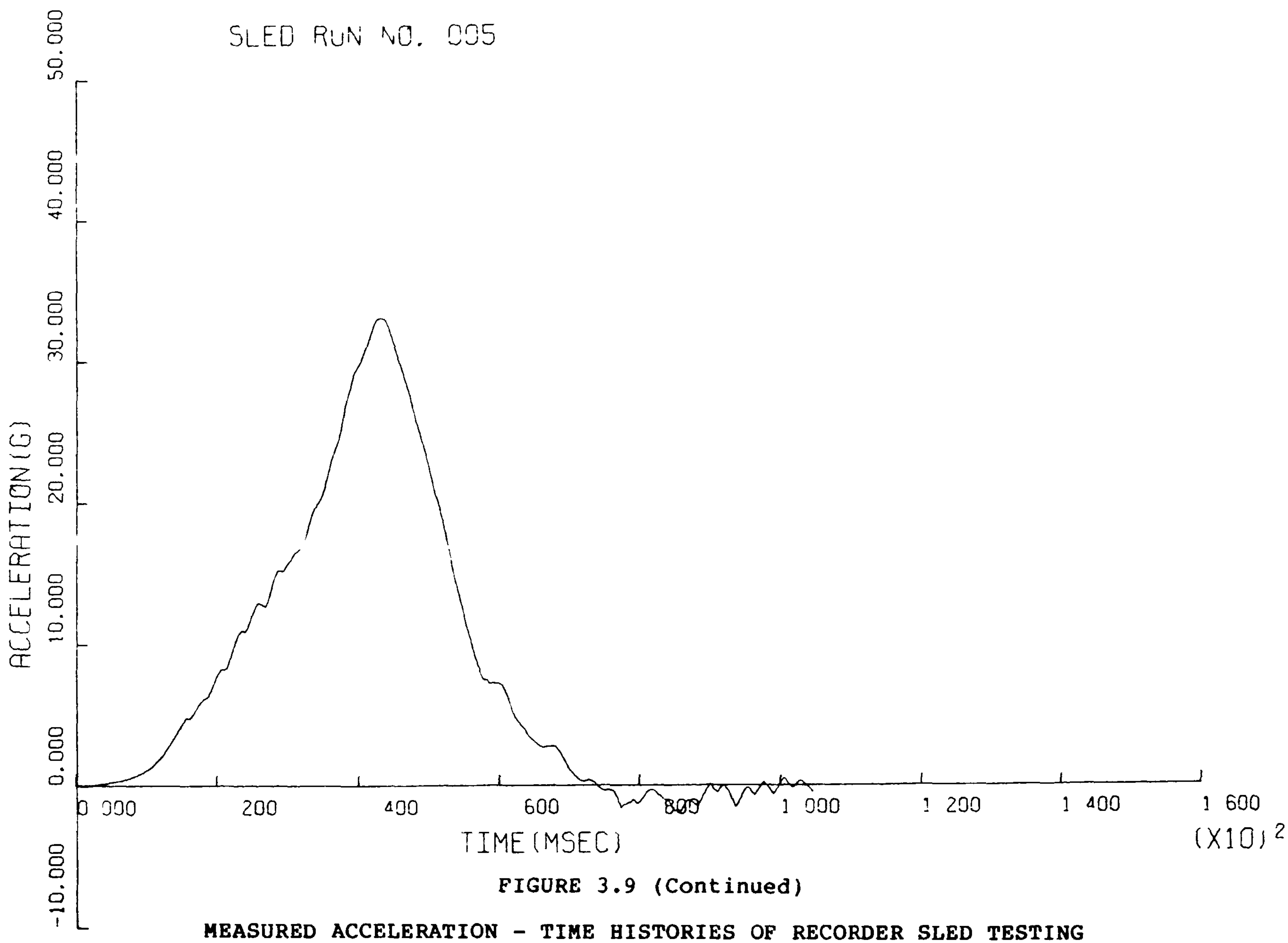


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

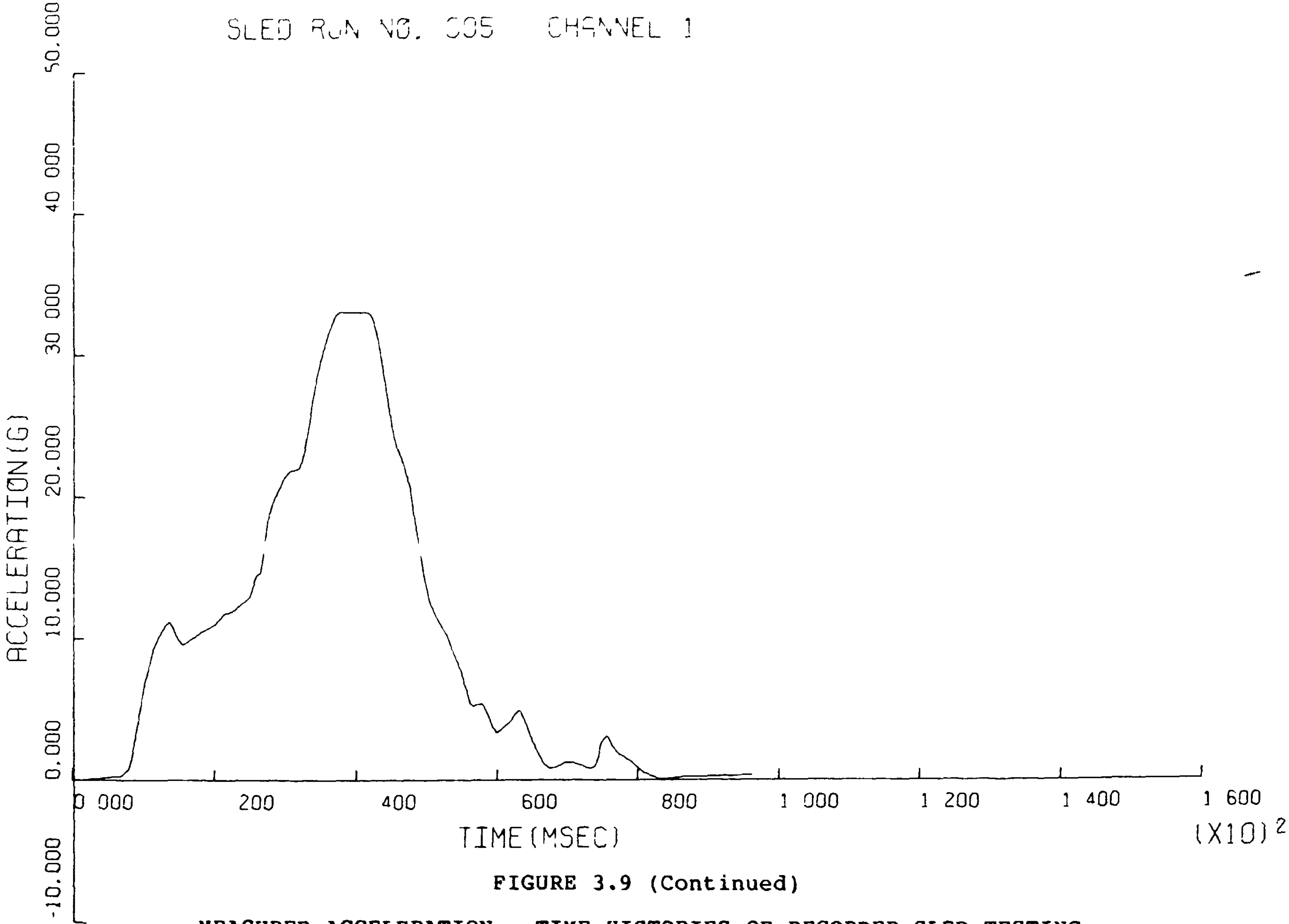


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

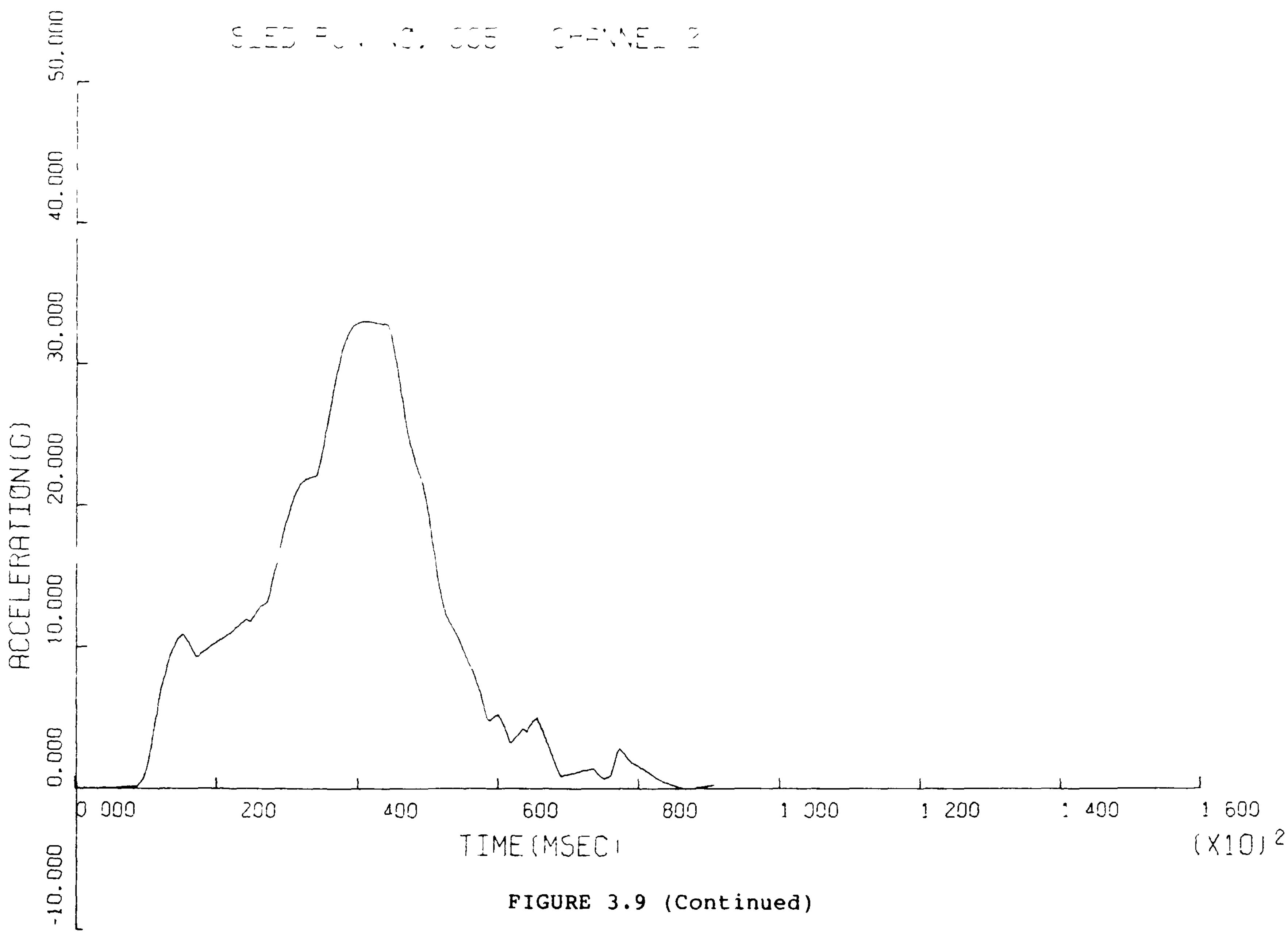


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

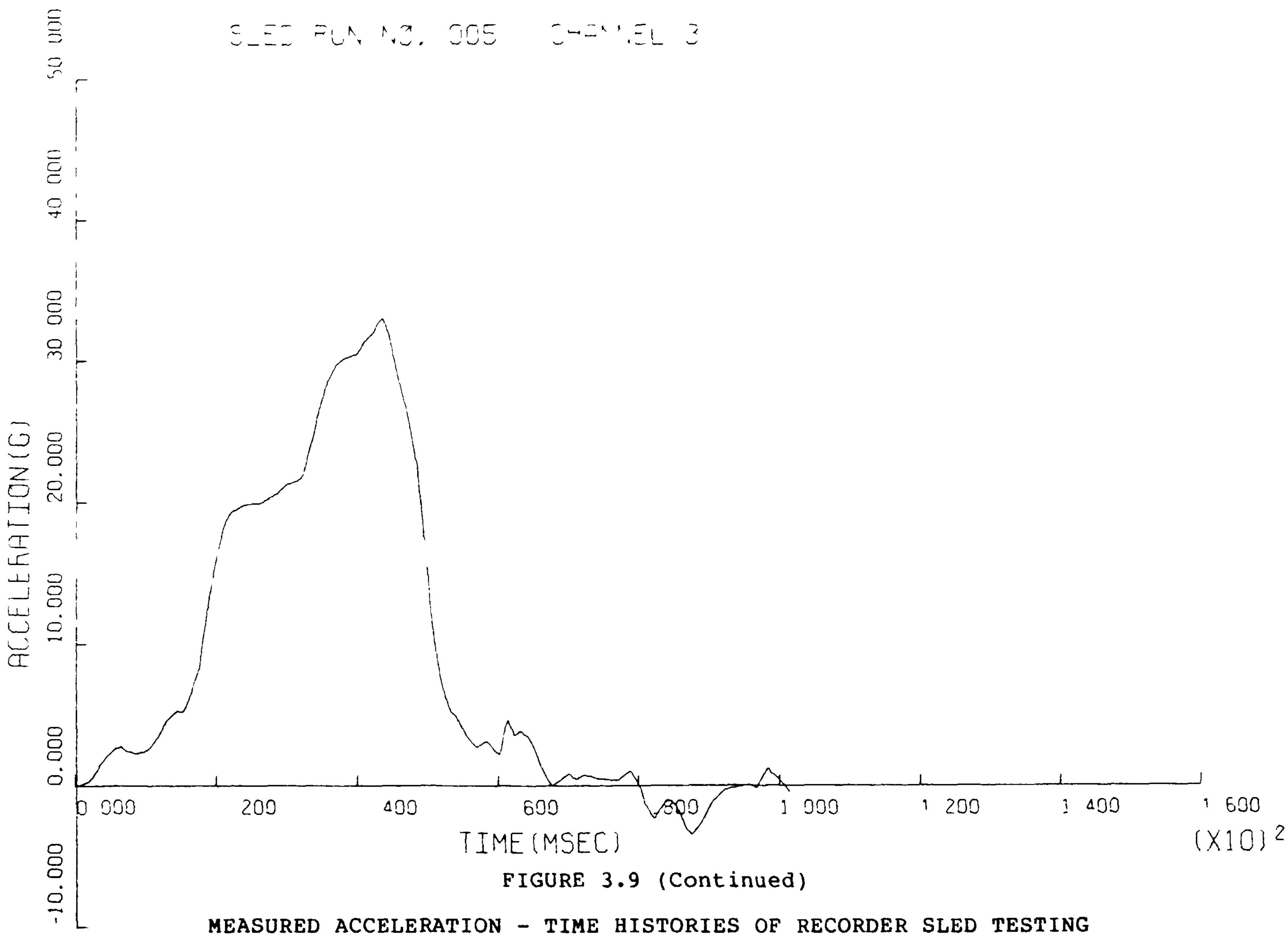


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

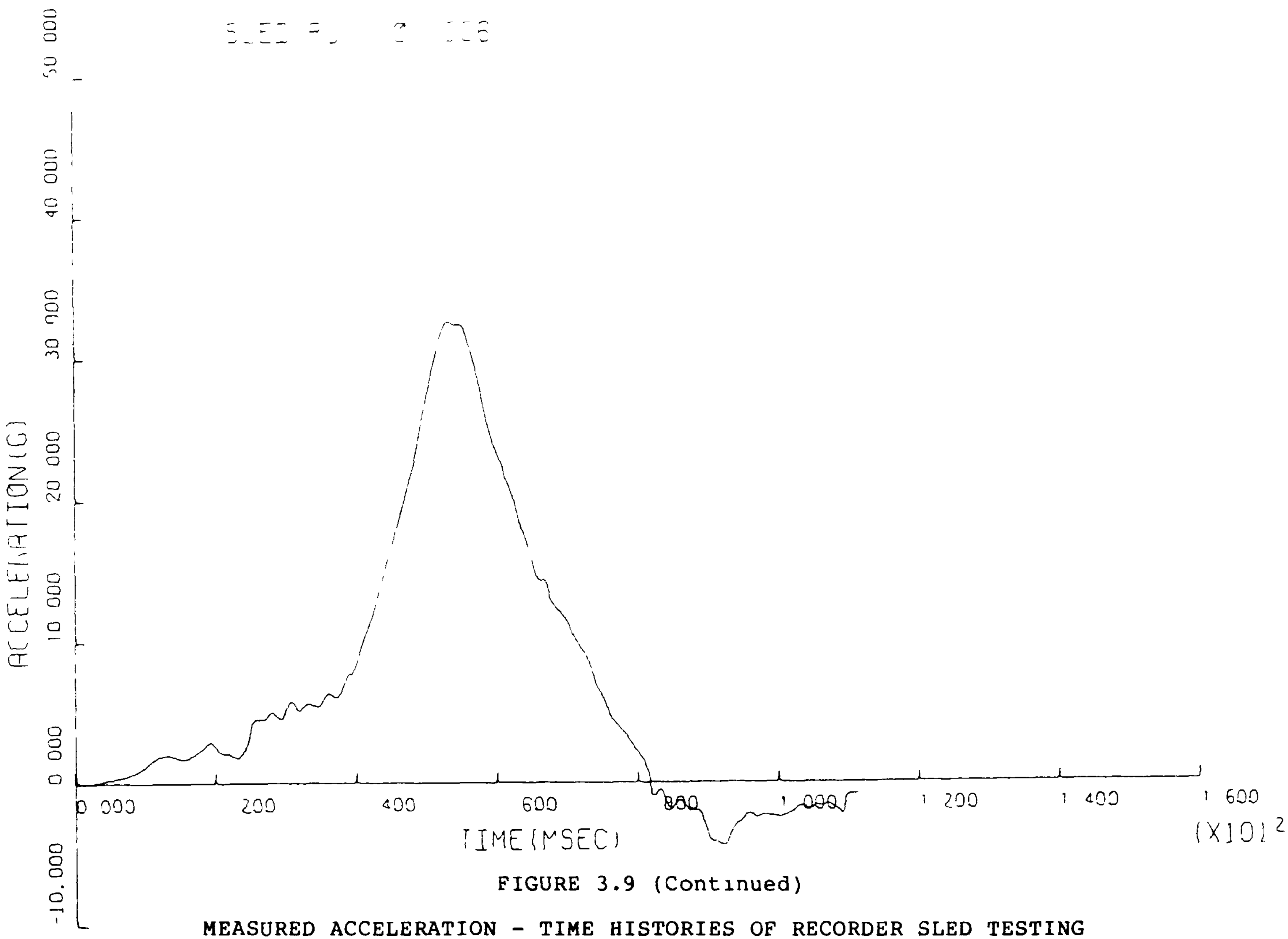


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

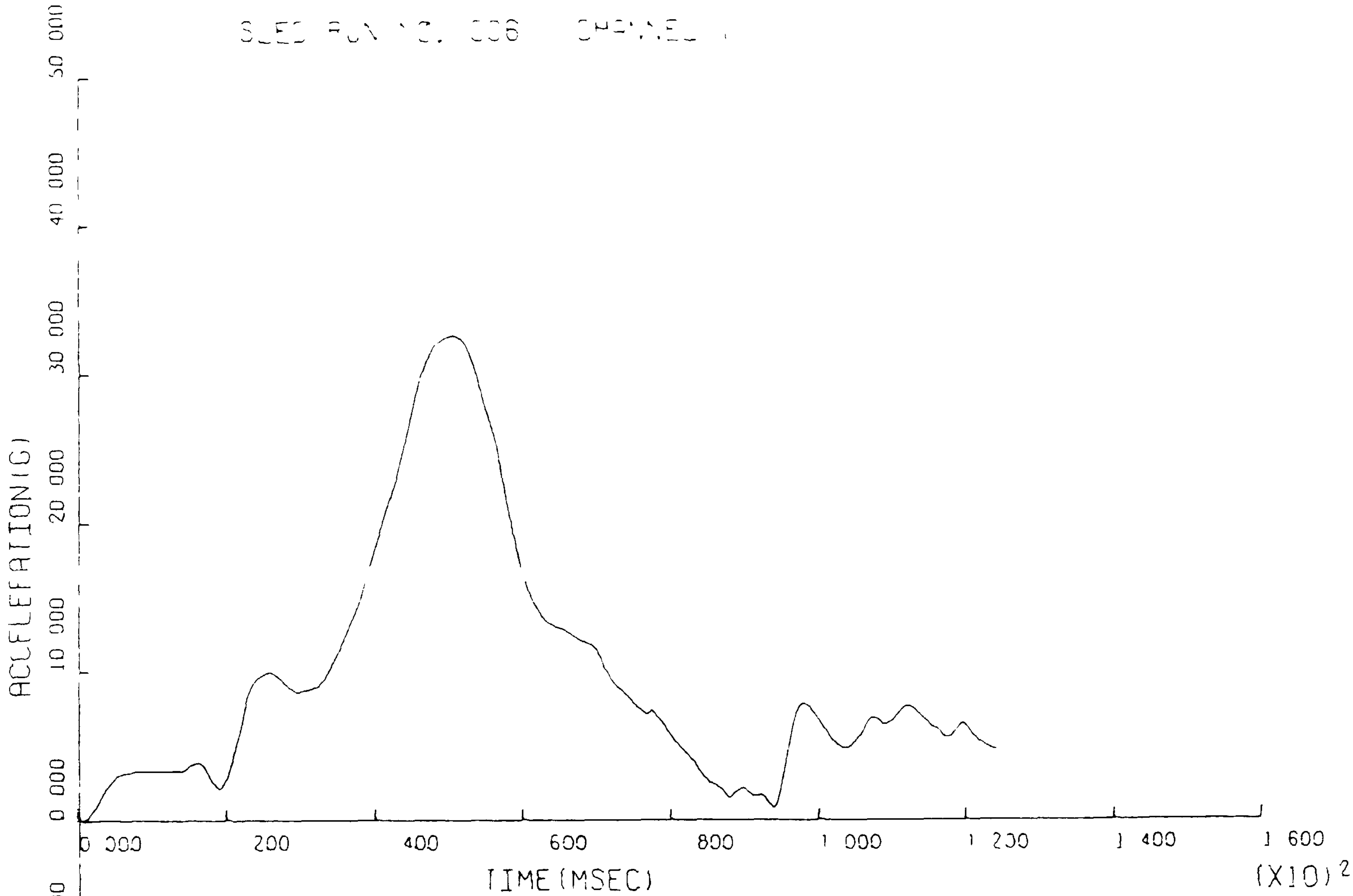


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

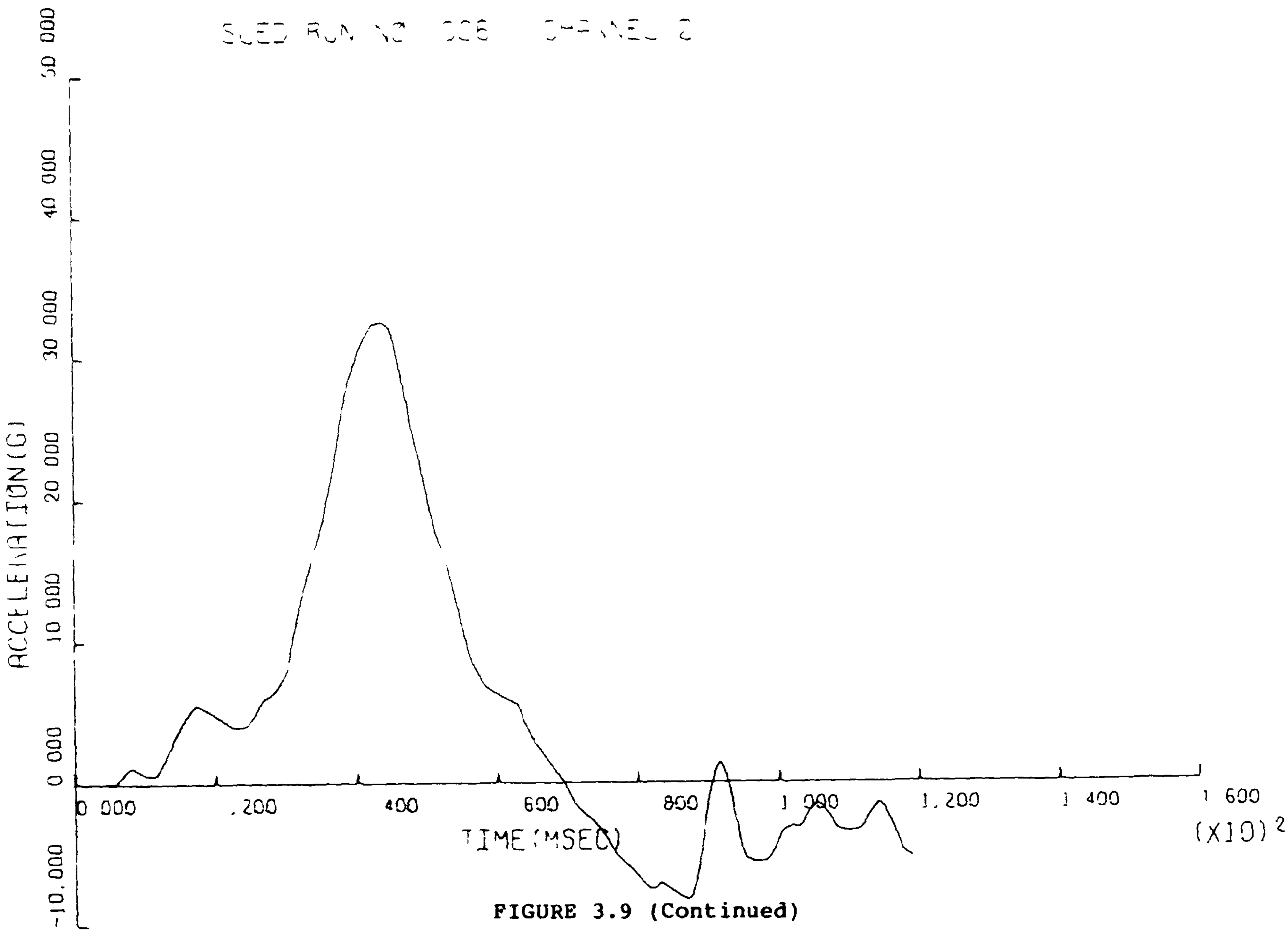


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

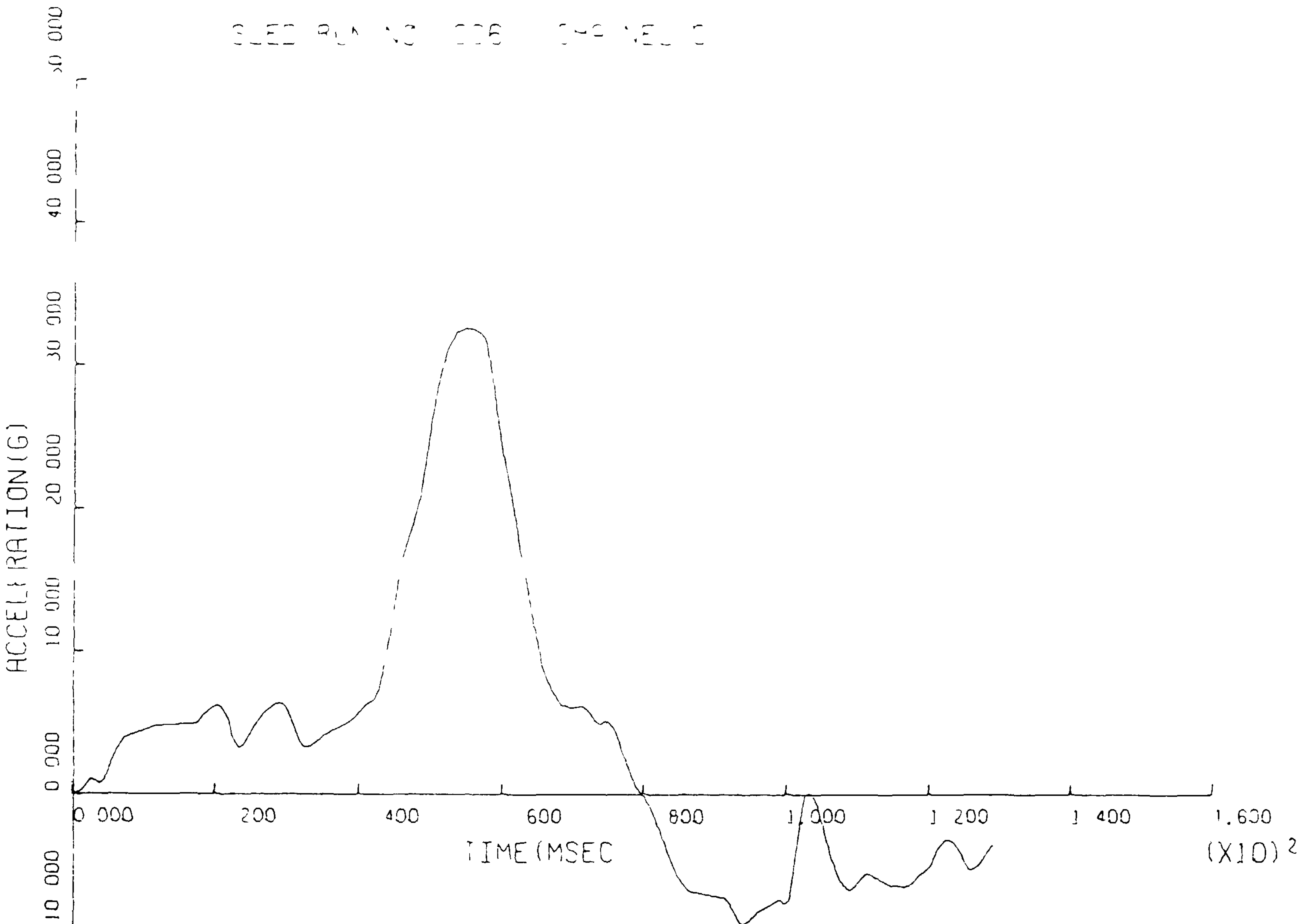


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

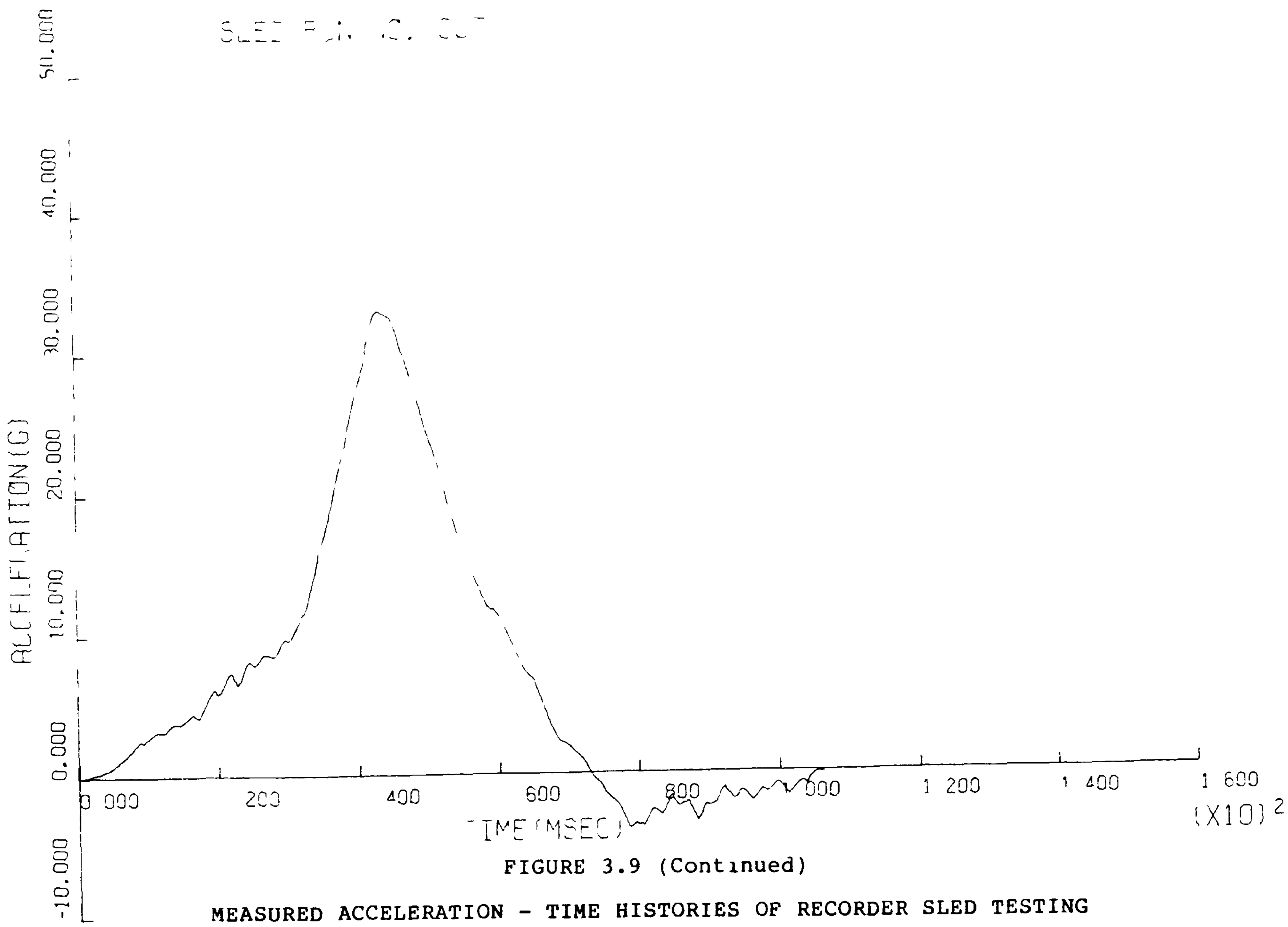


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

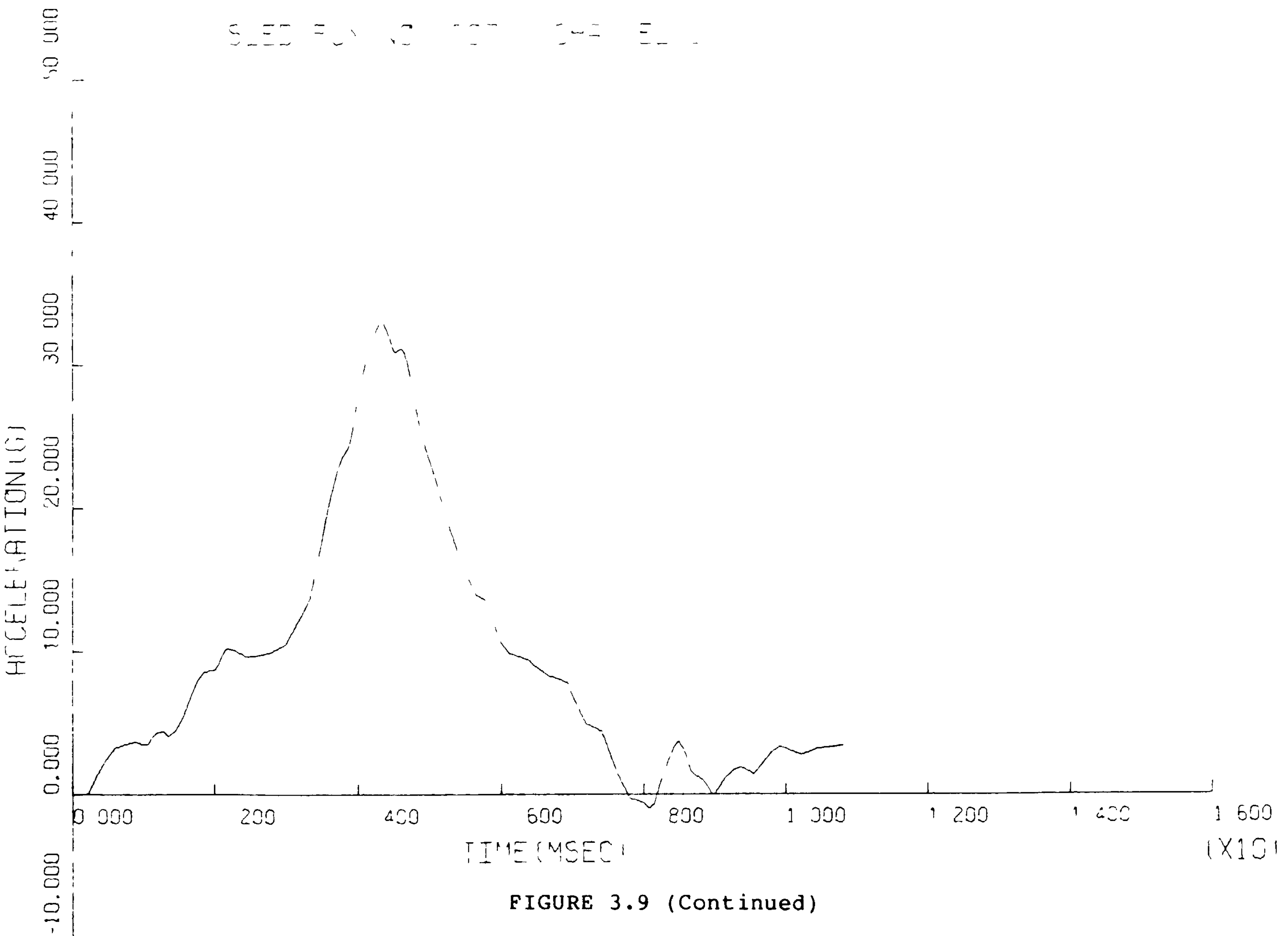


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

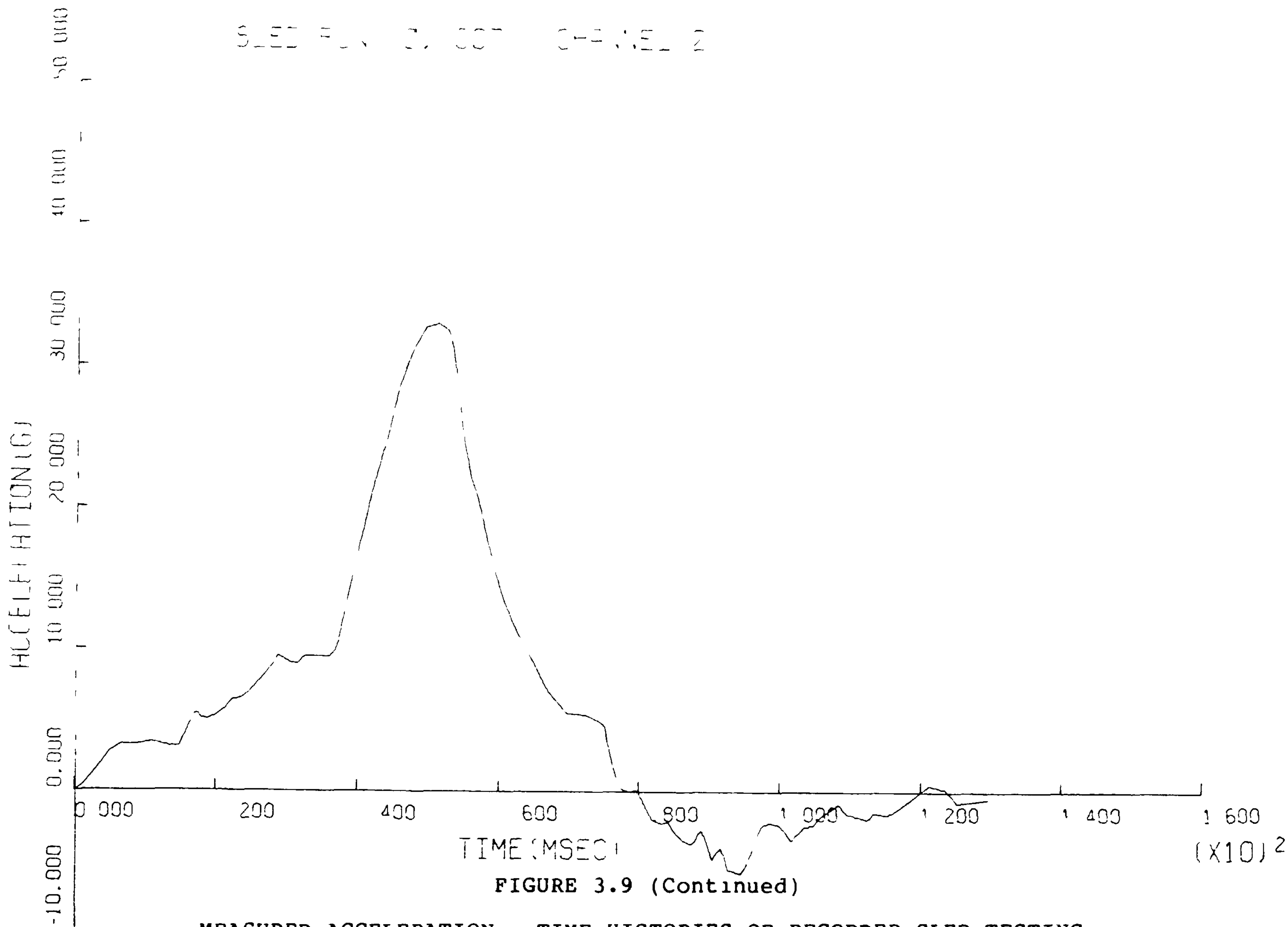


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

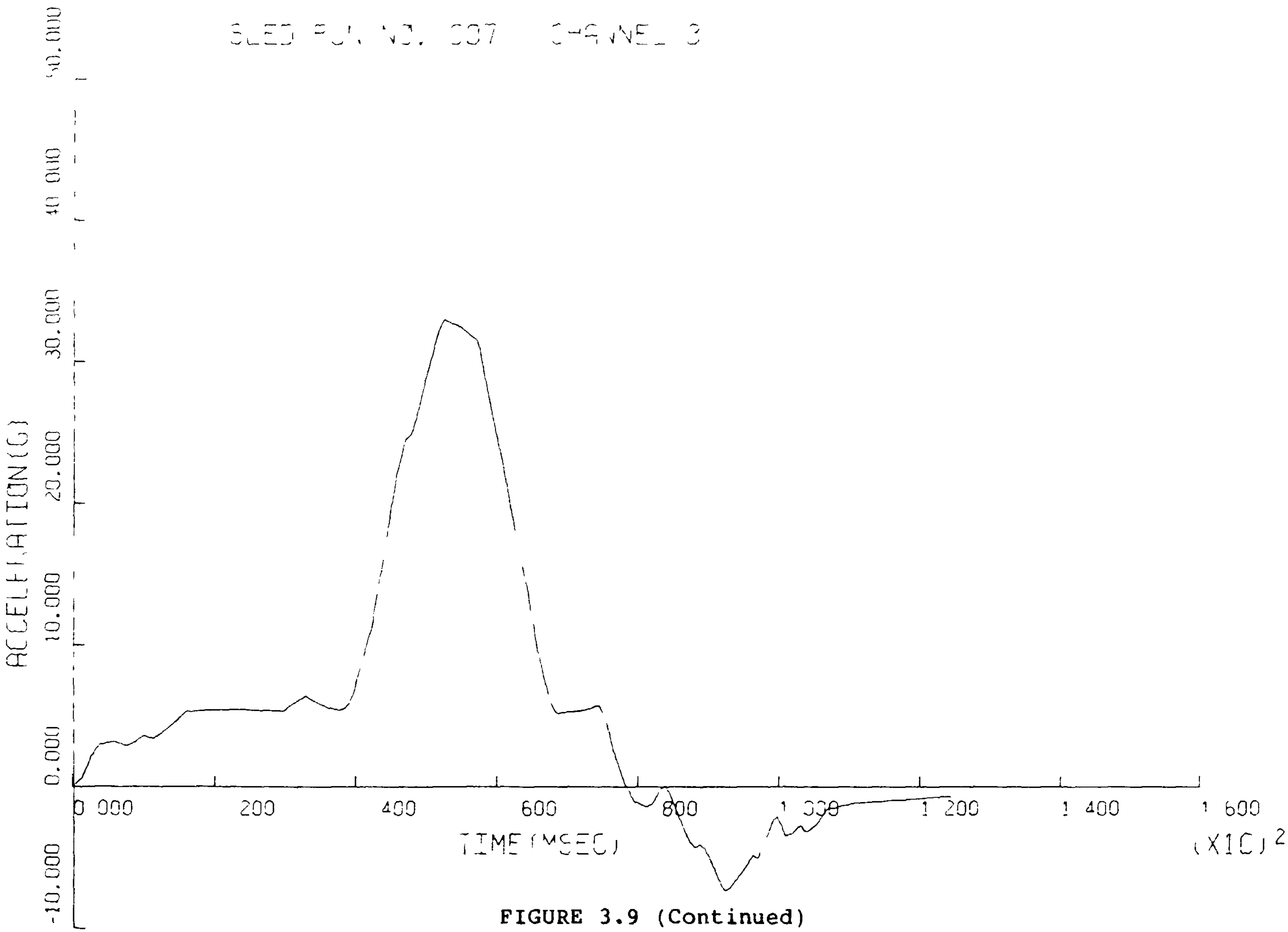


FIGURE 3.9 (Continued)

MEASURED ACCELERATION - TIME HISTORIES OF RECORDER SLED TESTING

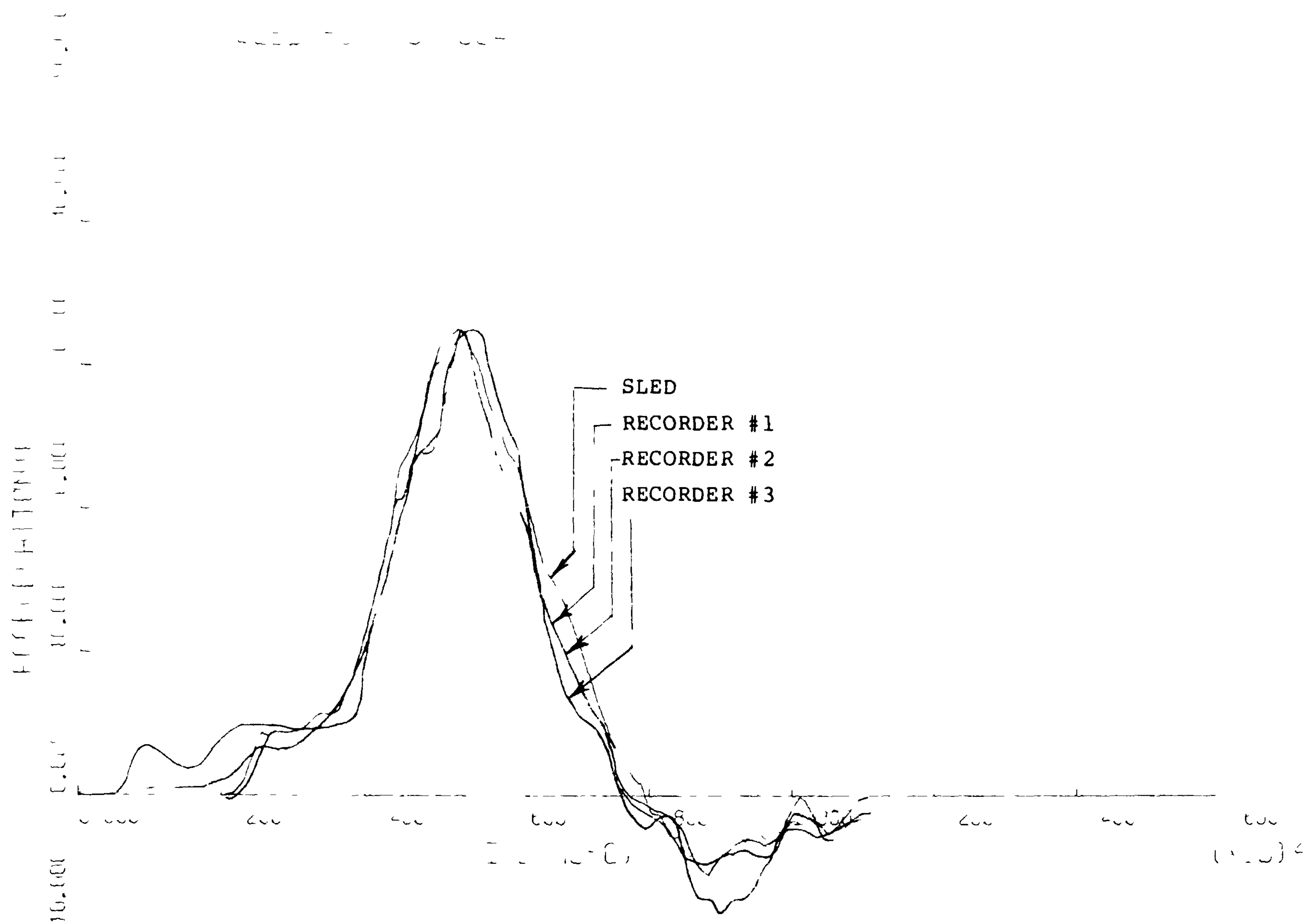


FIGURE 3.10

OVERLAY OF SLED TEST DATA FOR RUN NUMBER 004

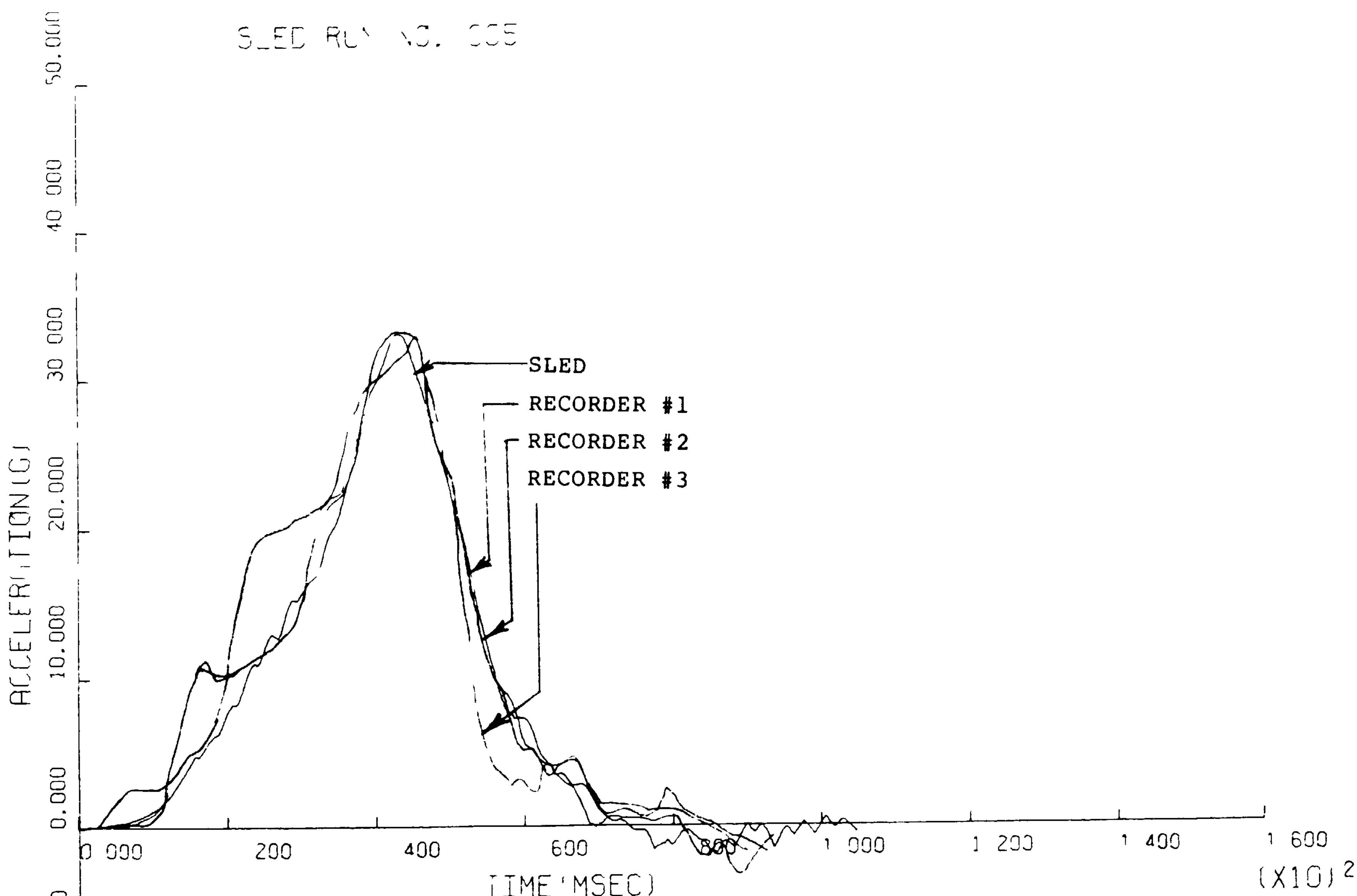


FIGURE 3.11

OVERLAY OF SLED TEST DATA FOR RUN NUMBER 005

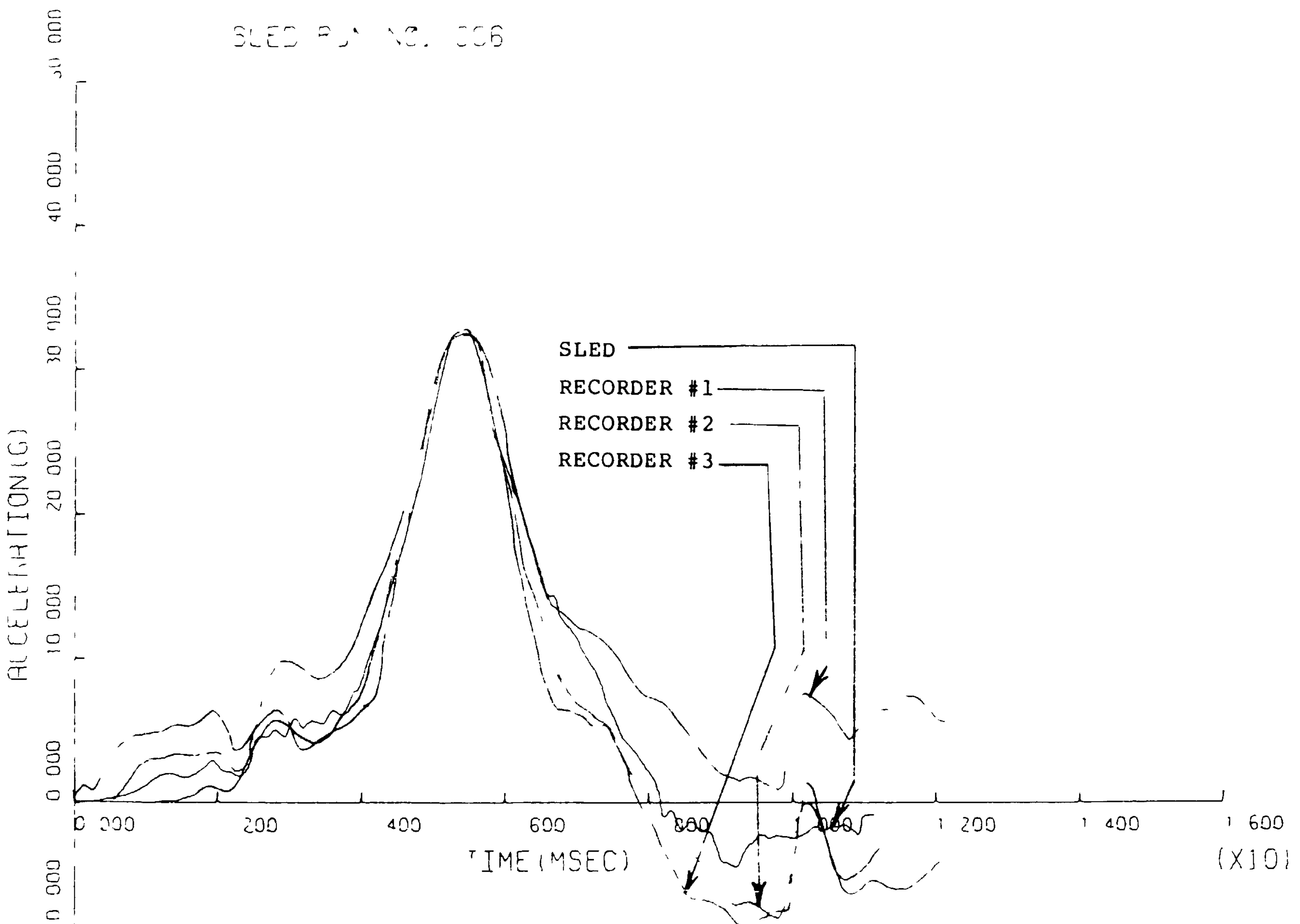


FIGURE 3.12

OVERLAY OF SLED TEST DATA FOR RUN NUMBER 006

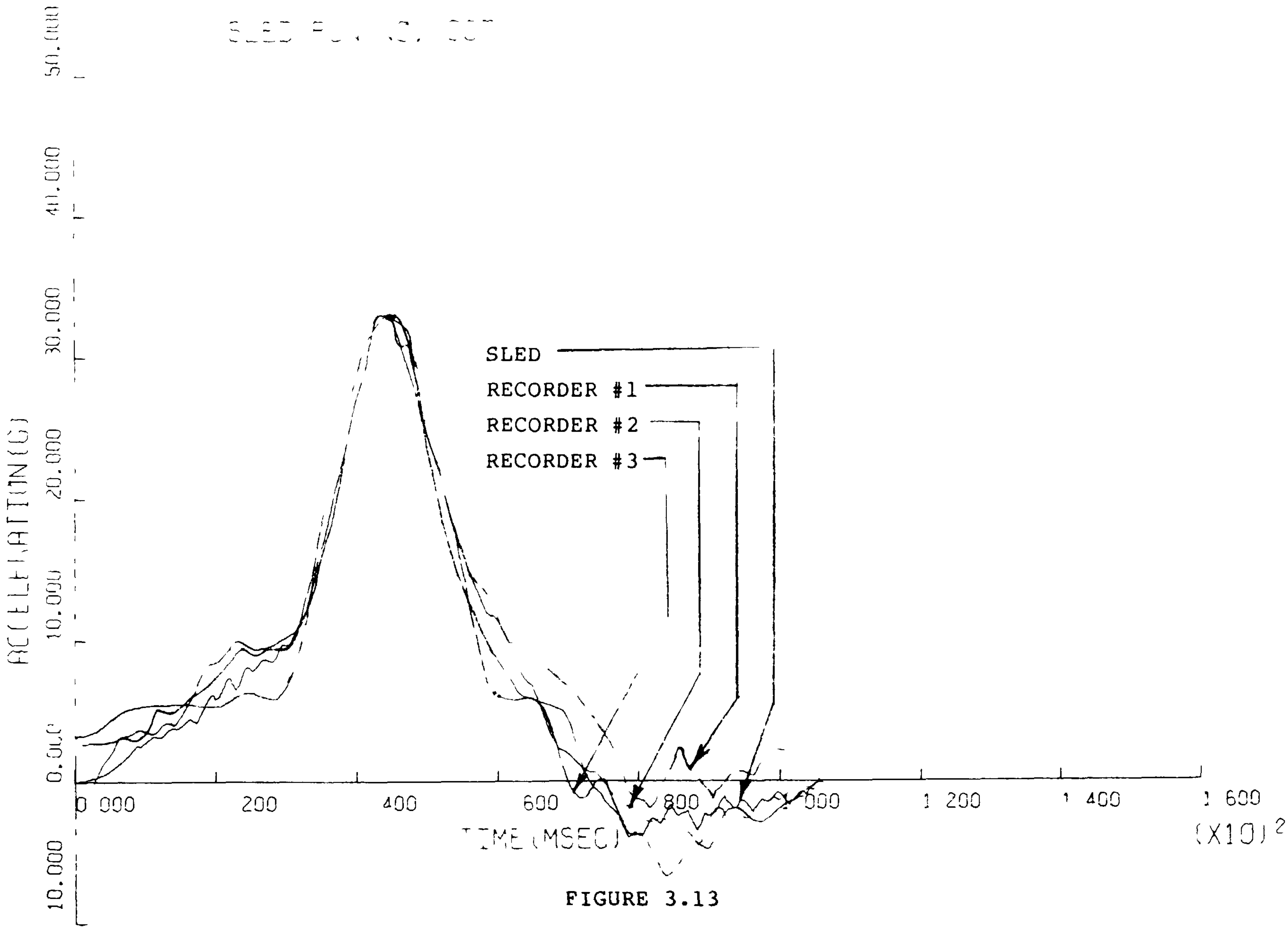


FIGURE 3.13

OVERLAY OF SLED TEST DATA FOR RUN NUMBER 007

4.0 VEHICLE TEST EVALUATION

An effort was made to evaluate the crash recorder during actual vehicle barrier impact and rollover events. This was to be done by "piggybacking" the recorder on instrumented impacts when they became available. A test series was participated in but an intermittent open circuit within the recorder's memory address generator rendered the recorder nonoperational for this test series. The problem was not diagnosed until after the vehicle test series.

The shaker, pneumatic shock machine, and testing sled described in the previous section, timewise, occurred after the unsuccessful vehicle test series and after the problem was determined and repairs implemented.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 General Conclusions

A nine channel 0.28 megabit solid state recorder, has been developed and evaluated in the laboratory, in sled simulated vehicle crashes and in vehicle crash environments. The recorder successfully captured, stored and read out impact information on shock machine testing, functioned properly during laboratory shock and vibration testing and during sled testing, but was inoperative during available piggyback vehicle impact tests.

5.2 Specific Project Conclusions

A number of specific conclusions are summarized below.

- The recorder stores and reproduces crash acceleration time histories as to shape and amplitude comparable to data obtained by conventional hard wire data acquisition system.

- The triggering of the recorder store mode obtained by a preset level, or by a preset level and duration, or by an external brake wire appears to be adequate for crash testing applications.

- The solid state digital data crash recorder is a significant technical advancement in data acquisition associated with automotive crash environments.

- This on-board recording concept simplifies the existing crash test procedures considerably and shortens the preparation time for test in the laboratory and vehicle crash environment.

The vehicle crash recorder system in its current stage of development is suitable for data acquisition in barrier impact, vehicle-vehicle and rollover crash testing.

5.3 Recorder Configuration Change Recommendations

On the basis of the system test experience obtained during this program, there are a number of suggested configuration changes which would further simplify field testing with the recorder system. These suggested configuration changes are summarized below.

5.3.1 Channel Gain and Offset Control Location

At present the recorder individual channel preamplifier gain and offset is adjusted by selection and replacement of individual discrete resistors on each channel electronics. This has proven to be inconvenient in field applications, because it requires the recorder to be disassembled in the event that sensors or channel sensitivities need to be changed. It would be much more convenient if these gain and offset resistor connections were brought out to an external connector on the recorder for easy field access.

5.3.2 Accessibility of Trigger Level Setting

At present selection and setting of the internal trigger level must also be done with the recorder disassembled which also is inconvenient in field applications. This input could also be provided by providing an external trigger level select switch.

5.4 Suggested Further Activity

The results and conclusions of this overall project suggest that a number of activities could be undertaken which would greatly increase the utility of this on-board recording technology and potentially reduce overall automotive crash testing costs.

5.4.1 Recorder Size Reduction

In its present configuration, the recorder system is packaged totally within the 8" x 8" x 8" envelope and weighs 16.4 lbs including the battery. The overall recorder system size is somewhat larger than might be desired if a large number of channels is required. It is not envisioned that this will affect loadings and the kinematics of even small vehicle barrier impact tests, but it may become awkward to handle too large and heavy a package in a field environment.

With the present functional configuration and packaging technology, the system is about as small as it can get. However, if hybrid-thin film fabrication were utilized, the physical size of the recorder could be reduced from its present 512 in^3 to ~20 in^3. This would imply that the physical size of the system would then be dominated by the size of the battery pack. Power consumption (battery size) could also be reduced by employing lower power sensors and a lower power memory (CMOS RAM).

5.4.2 Recorder Readout Support Equipment

To date the primary recorder output mode utilized has been the analog format. This analog signal is typically transferred to a tape deck which is then usually converted back into a digital record for analysis. Overall this requires extensive involvement of test facility personnel to transfer data from the recorder, format it and output it on a permanent record. The recorder presently has a digital data output mode which can be utilized in connection with a plotter to output data in scaled, physical units in report ready format. This system could be made an integral part of the "data readout box" and would allow on-sight plotting of impact data, further simplifying test and data reduction procedures.

5.4.3 Recommendations

- It is recommended that the recorder channel gain and offset control be provided as an external connection to the recorder, perhaps as part of sensor connectors.

- It is recommended that the internal trigger level select be provided as an external switch.

- It is recommended that vehicle crash testing be conducted so that more field experience with the vehicle recorder can be accumulated.